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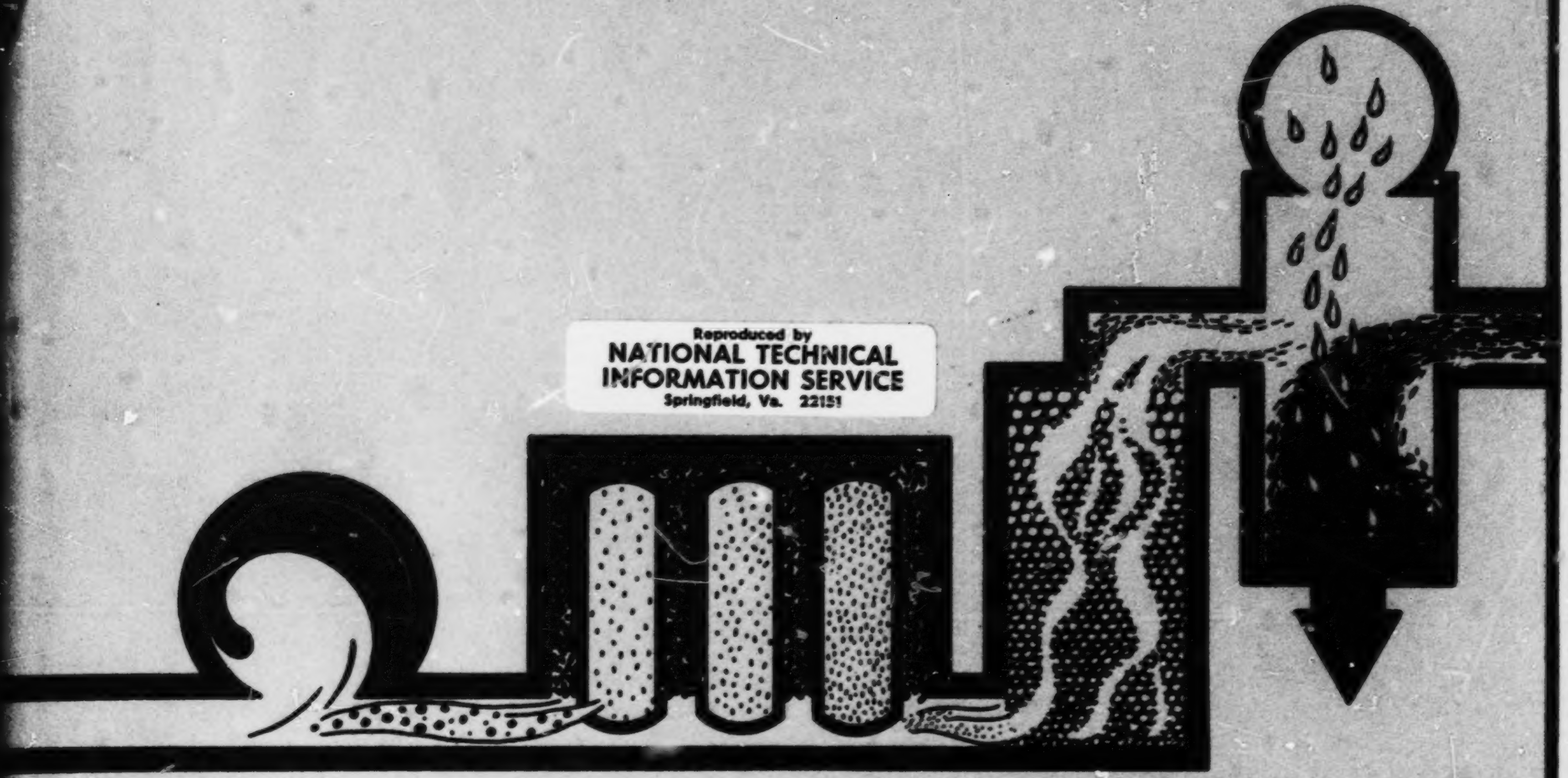

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27 Abstract
High levels of phosphorus removal have been observed at the Baltimore Sewage Plant in the past. A six month study of the operating conditions and design parameters of two parallel, 10 MGD activated sludge systems was conducted in an attempt to establish the mechanism by which the phosphate was removed. The following variables were used: suspended solids concentration, waste water flow, aeration basin mixing configuration, and dissolved oxygen levels. Both mixing and dissolved oxygen were shown to influence the process greatly. Contact stabilization or step aeration, as opposed to plug flow, caused sharp decreases in the removals, while low dissolved oxygen levels stimulated releases of phosphorus from the sludge. Operating conditions which enhance phosphate removal are standard conditions now at the Baltimore plant. Phosphate removal at Baltimore averaged 82% , compared with 15 to 20% removals for conventional activated sludge, and 9% in Baltimore's trickling filter. No cost analysis was undertaken, since complete removal of the phosphorus involves removal from the sludge supernatant. Some of the parameters which may lead to enhanced phosphate removals have been demonstrated. However, the exact reaction or mechanism by which the removals proceed is still unknown, even though it was established that the calcium removed from the system was not principally by precipitation. (Lowry-Texas)

(WSIC abstract)

Abstractor Mark V. Lowry
Institution Texas Univ, Austin

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PHOSPHATE STUDY AT THE BALTIMORE BACK RIVER WASTEWATER TREATMENT PLANT

by

The City of Baltimore, Maryland

for the

WATER QUALITY OFFICE

ENVIRONMENTAL PROTECTION AGENCY

Program #17010 DFV
Contract #14-12-471
WQO Project Officer, E. F. Barth
Advanced Waste Treatment Research Laboratory
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ABSTRACT

Two parallel 10-mgd activated sludge systems at the Baltimore Sewage Treatment Plant were used in a six-month study to evaluate the effects of operating conditions and design parameters on the previously observed high degree of phosphorus removal. An automatic, multi-parameter monitoring system provided immediate readout and continuous recording of key operating data.

Suspended solids, wastewater flow, aeration basin mixing configuration, and dissolved oxygen were evaluated for the effect on phosphorus removal. Neither suspended solids (1,200 to 3,900 mg/L) nor flow (aeration detention times ranging from 2.7 to 12 hours) showed an influence on phosphorus removal. However, changing from plug flow to step aeration or contact stabilization greatly impaired the phosphorus removal. Low dissolved oxygen levels stimulated sharp releases of phosphorus, which were accompanied by impairment of organic removal. Slug wasting of excess activated sludge also appeared to impair phosphorus removal.

Phosphate removal in the control system averaged 82 percent which is in sharp contrast to the 15 to 20 percent phosphorus removal capability that is typical of activated sludge systems and the 9 percent removal observed in Baltimore's trickling filter.

At Baltimore, operating conditions are specified for maximum phosphorus removal. However, no estimate of cost for this mode of operation is presented because the critical removal of phosphorus from sludge-handling supernatants was beyond the scope of this study.

The reaction mechanism of phosphorus removal was not clearly demonstrated. However, calcium removals showed that calcium phosphate precipitation was not the principal factor.

This report was submitted in fulfillment of Contract No. 14-12-471, Program No. 17010 DFV, between the Federal Water Quality Administration and the City of Baltimore.

Keywords: Activated Sludge, Aeration, Analysis, Automation, Monitoring, Municipal Wastes, Nutrients, Oxygen Demand, Phosphorus, Remote Sensing

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SECTION I

CONCLUSIONS

1. The objective of this study was the full-scale process demonstration and evaluation of operating parameters of activated sludge phosphorus removal and did not include the theoretical determination of the specific mechanisms or processes that accomplish this phosphorus removal. The long-term observations accumulated in this Study demonstrate that the reality of phosphorus removal at Baltimore and the operating conditions found necessary for optimum activated sludge phosphorus removal are within the capabilities of the existing Baltimore system. However, a substantiated explanation of the precise mechanism of phosphorus removal was not found in this study, and further study (with this as specific objective) is needed. At Baltimore, long-term calcium and pH observations indicate that precipitation of the phosphorus by calcium was not accounting for the abnormally high phosphorus removal.

2. During the last 4 months of the Baltimore field study, when the monitoring system was most effective and adequate aeration was applied, full-scale control activated sludge system averaged an ortho-phosphate removal of 90 percent and a total phosphorus removal of 82 percent. Ninety percent of the time the system removal was greater than 72 percent for total phosphorus. The maximum phosphorus removal observed for any one-month period on the control system averaged 92 percent.

3. The total phosphorus content of the activated sludge was normally between 3 and 5 percent. The concentration of suspended solids in the final effluent was normally between 10 and 30 mg/L. Thus, it would appear that a major portion of the phosphorus in the final effluent can be attributed to the phosphorus in the suspended solids. (Filtered and unfiltered analyses were not routinely performed on the secondary effluent).

4. Dissolved oxygen concentrations in the activated sludge aeration tank had an important influence on phosphorus removal. It was necessary to maintain approximately 2-3 mg/L of oxygen at the end of the plug flow aeration tank to achieve successful phosphorus removal. A significant phosphate release in the effluent was caused by lower levels of dissolved oxygen at the end of aeration, which for the particular aeration tanks under study, represented zero dissolved oxygen in a large portion of the tank. A cycle of release and recovery was observed to be reproducible on a daily basis. Limited oxidation reduction potential (ORP) observations were made during the low aeration phosphorus releases and showed no advantages over dissolved oxygen as a monitoring parameter for control of this condition.

5. Whenever a phosphorus release related to a low dissolved oxygen level occurred, an accompanying reduction in carbon removal was also observed. Therefore, an oxygen-limiting condition appeared to exist on system performance at these times.

6. An automatic sampling and analytical system was developed and successfully used to provide immediate knowledge of plant performance and continuous monitoring data, (particularly on phosphate and carbon removal), which were essential for the daily dissolved oxygen variation test.

7. The concentration of mixed liquor suspended solids was not observed to be an important factor during the study at Baltimore. Phosphorus removal was successful within the range of 1,200 mg/L to 3,700 mg/L of suspended solids. There was some indication that phosphorus removal may have been decreased when suspended solids concentration was in the 600-900 mg/L range.

8. Secondary Clarifier sludge depth, which was greatly increased during bulking conditions, did not affect phosphorus removal. However, an efficient sludge removal mechanism did keep sludge residence time to a minimum in the Baltimore system.

9. Wasting of excess activated sludge at abnormally high rates during intermittent periods was observed to upset phosphorus removal; therefore, continuous sludge wasting at controlled rates in necessary for effective operation.

10. Hydraulic loading variations (diurnal alternations of aeration tank theoretical detention time 5.5 to 12 hours, and constant operation at detention times ranging from 2.7 to 11.5 hours) did not adversely affect the activated sludge phosphorus removal.

11. The mixing configuration in the aeration basin was an important factor in the removal of phosphorus. Only a plug flow configuration was successful during the Study at Baltimore. Contact-stabilization and step aeration configurations were examined in full-scale for limited periods of time and were not successful; contact-stabilization, step aeration, and completely-mixed configurations were unsuccessful in the laboratory.

12. When phosphorus removal was taking place in the plug-flow activated sludge system, an obvious release of phosphorus took place at the inlet of the aeration tank, and a subsequent uptake of phosphorus occurred at a later point in the flow path system. A release and uptake of magnesium ion coincided with the phosphorus concentration pattern.

13. An increase in pH was always observed across the plug-flow aeration tank, and maximum pH levels at the end of the aeration tank for the study averaged 7.1 and ranged between 6.7 and 7.4.

14. Throughout the Study, the primary effluent phosphorus content of both primary and secondary effluents did not show any correlations with the nitrogenous and carbonaceous substances.

15. The overall average of metal ion concentrations at Baltimore did not appear abnormally high nor show abnormal removals. The average changes in metal ion concentrations for the control system primary effluent and the secondary effluent were: calcium 25.3 and 23.6 mg/L; magnesium 11.2 and 8.1 mg/L; iron 3.2 and 0.9 mg/L; aluminum 2.1 and 0.7 mg/L; zinc 1.0 and 0.3 mg/L; and copper 0.4 and 0.1 mg/L. The total metal ion removal could, on an ideal stoichiometrical basis, barely account for the phosphorus removal.

16. Long-term sampling of the low-rate trickling filter system at Baltimore indicated a 9 percent phosphorus removal, which was the approximate quantity required for biological synthesis in the system.

17. The phosphorus removed in the Baltimore activated sludge system is transported in a phosphorus-rich excess activated sludge stream, and the overall flow configuration of the Baltimore Back River Plant is such that only approximately 12 percent of any phosphorus released in subsequent sludge handling operations returns to the activated sludge system.

18. The added cost for full development of effective activated sludge phosphorus removal at Baltimore (or other possible conventional activated sludge systems) would include the expense necessary to prevent recycle of soluble phosphorus degradation products from sludge handling operations and the expense for minor aeration tank modifications and providing adequate aeration capacity.

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SECTION II

INTRODUCTION

The water quality of a number of streams and lakes is currently deteriorating because of increased algal and plant growth. An increase in the phosphorus content of these waters frequently has been cited as the cause for these changes, and as a result, some regulatory agencies are requiring a high degree of phosphorus removal in the treatment of domestic wastewaters. When secondary biological treatment is applied, domestic wastewaters are deficient in carbon and rich in phosphorus and nitrogen for normal microorganism needs. In general, the secondary treatment of domestic wastewater by the production of microorganisms (such as activated sludge) will satisfactorily remove most of the organic carbon but will usually produce an effluent which still contains a large proportion of the incoming phosphorus and nitrogen.

However, a limited number of existing conventional activated sludge plants across the United States have demonstrated abnormally high phosphate removal efficiencies, without the specific addition of chemical precipitating agents. Since there is a potential for application elsewhere of this approach to significant reduction of phosphorus, there is interest in full-scale, long-term demonstration, definition, optimization, and specification of critical operating and design parameters for this process.

The project objectives of the field study at the activated sludge portion of the Back River Wastewater Treatment Plant in Baltimore, Maryland (by the City of Baltimore, under the technical direction of ROY F. WESTON) are as follows:

1. Process Demonstration - To observe phosphorus removal over a sustained period, with intensive monitoring of operation and treatment parameters.

2. Process Definition - To further define the limitations on input conditions under which phosphorus removal can be accomplished in a continuous flow, full-scale, conventional activated sludge process by investigation of parameter interactions and process kinetics.

3. Process Specification - To verify and quantify within the limitations of available facilities, the specific design and operating parameters of the treatment system for possible application to phosphorus removal at other wastewater treatment plants.

Theoretical Considerations

An activated sludge plant treating domestic wastewater normally achieves a phosphate removal of 20-30 percent. However, at least five conventional activated sludge plants at different locations across the United States have been documented as achieving a phosphate removal of 60-95 percent consistently. The currently-advocated theoretical explanations for this high phosphate removal phenomenon can be grouped in two categories: 1) the occurrence of luxury biological uptake and biologically-enhanced precipitation of phosphate; or 2) metal precipitation of phosphorus, dependent on the mineral content of the wastewater and essentially independent of the presence of biological organisms. Either of these explanations could account for the soluble-to-solid transfer of phosphate phosphorus in the activated sludge process; however, the two explanations do represent significantly different implications on the manner and extent to which this phosphate removal process can be applied to domestic wastewater treatment. If the phosphate removal mechanism is a true luxury biological uptake phenomenon dependent primarily on the biological solids present, the process should be applicable to any domestic wastewater where the appropriate process design and operating conditions are maintained to grow the desired biological population. However, if the phosphate removal mechanism is largely one of chemical precipitation and a function of the specific mineral content of the wastewater, application of this process would be restricted to those areas where the "correct" wastewater characteristics are available.

In the literature, probably the first use of the luxury biological phosphorus uptake explanation for the phosphate removal in the activated sludge process was that of Levine and Shapiro (1). They observed very high phosphate removals by activated sludge in batch studies. As a mechanistic explanation they hypothesized that in aerobic utilization of carbohydrates, the high participation of phosphorus in metabolism and the metabolic intermediates favor the luxury uptake of ortho-phosphate in microorganisms. Their batch experiments showed that this phenomenon was dependent on the dissolved oxygen concentration. To confirm the biological nature of the observed luxury phosphorus uptake, they significantly diminished the phosphorus removal in activated sludge by adding small amounts of dinitrophenol, which specifically inhibits biological oxidative phosphorylation.

Smith, et al. (2) similarly found that the presence of dinitrophenol inhibited the formation of intercellular volutin granules and the associated increase in total phosphorus content of cells in pure culture of the common bacteria Aerobacter Aerogenes. They observed that an aerobic subculture of Aerobacter Aerogenes (cultivated on a phosphorus media) growing on adequate media showed a 2- to 3-fold increase in total cellular phosphorus, a 200-fold increase in intercellular inorganic meta-phosphate, and the production of many intercellular volutin granules. In their experimentation, they found volutin granules were produced only if sufficient glucose, phosphorus, magnesium, and potassium were present in the media. This phosphate-starved activation property for subsequent 2- to 3-fold increase in cellular phosphorus has been reported by Borchardt et al. (3) for algae grown in both light and dark conditions.

Furthermore, Harold (4) described intercellular volutin as consisting mainly of inorganic poly-phosphates including some magnesium, protein, lipid, and other substances. He indicated that the use of the enzyme phosphate kinase appeared to be the only pathway for the biosynthesis of long-chain poly-phosphate molecules; the presence of magnesium is required for this particular enzyme activity. Although poly-phosphate kinase was first identified in yeast, it is widely distributed among microorganisms, many of which are very common in the activated sludge biomass. There are many cellular enzymes that can be found to degrade poly-phosphate molecules, indicating that there is no problem in the re-utilization of phosphorus stored in the poly-phosphate form.

In contrast to the above approach is the theoretical explanation involving chemical precipitation. This position is most clearly described by Menar and Jenkins (5), who hypothesize that phosphate removed in excess of that predicted by biological growth requirements (to produce an activated sludge of 2 to 3 percent phosphorus content) is accomplished by chemical precipitation, with the phosphate precipitate becoming physically entrapped in the matrix of the activated sludge floc and removed in the waste activated sludge stream. There is some claim that the activated sludge provides seeding or nuclei for the precipitate. In hardwater sewage, a significant part of the removal of phosphorus is thought to be caused by calcium precipitation. For this case, the hypothesis is that since calcium phosphate precipitation is a function of pH and since carbon dioxide stripping occurs in the latter phases of aeration in an activated sludge aeration tank, the pH is increased sufficiently to cause calcium precipitation. In some full-scale activated sludge systems where high phosphorus removal has been observed, significant removals of calcium have been associated with the phosphorus removal.

This chemical precipitation theory is supported by Ferguson et al. (6), who state that low magnesium and low carbonate concentrations encourage higher removals by calcium phosphate precipitation. They also found that the presence of calcium phosphate seed particles accelerated the calcium removal of phosphorus in sterile wastewater free of biological activity.

A high degree of phosphorus removal from municipal wastewaters by conventional activated sludge plants has been observed at San Antonio, Texas (7); Milwaukee, Wisconsin (8); Amarillo, Texas (9); Ft. Worth, Texas (9); and Los Angeles, California (10). Probably the most widely publicized cases of full-scale phosphate removal is that at San Antonio, Texas. One of three parallel activated sludge plants at the San Antonio Wastewater Treatment Plant has been observed to remove consistently a much higher percentage of phosphate than the two similar parallel plants. In all three plants, the supernatant or filtrate from the sludge-handling operations is not returned. As a result, a number of studies have been performed to evaluate significant parameters and operating aspects responsible for the differences in phosphorus removal.

Dissolved oxygen levels in the aeration of activated sludge have received considerable attention, and Wells (11) illustrates and discusses the release and uptake of phosphates by the San Antonio activated sludge plant during periods of aeration and non-aeration. The effect of aeration tank suspended solids concentration was also studied at San Antonio; in work presented by Witherow (9), increase of the aeration tank suspended solids concentration from the 500-1,000 mg/L range up to the 1,500-2,000 mg/L range increased the phosphorus removal in one of the San Antonio activated sludge plants (that normally achieved only a 30 to 40 percent reduction) to more than 90 percent. Many other operating parameters have been evaluated at San Antonio and have been the basis for a number of laboratory investigations. Yet, a full explanation of the phenomenon and definition of design parameters have not been achieved.

Efficient phosphorus removal in the activated sludge portion of the Baltimore, Maryland Back River Wastewater Treatment Plant was first reported by Alarcon (12) in 1961. He observed fluctuations in phosphorus removal which he suspected were associated with fluctuations in the rate of aeration. Confirmation of the high phosphorus removal at Baltimore was reported by Scalf et al. (13); during a two-week period in April 1967, the Baltimore activated sludge plant showed consistent phosphate removals of more than 90 percent. This particular study was performed by the Federal Government in a series of amenability tests for selection of a full-scale research plant to further specify, define, and optimize the parameters of the activated sludge phosphate removal process. As further confirmation for approving the research contract for the study described in this report, an additional series of samples from the Baltimore Back River Wastewater Treatment Plant, analyzed during the period May 13-23, 1968 by the Federal Government, again showed a consistently high degree of phosphate removal. After preliminary approval on October 15, 1968, the research contract for the extended full-scale demonstration and definition of phosphate removal was formally authorized on December 27, 1968 to the City of Baltimore, which then sub-contracted the majority of the services to ROY F. WESTON of West Chester, Pennsylvania.

To achieve conclusive documentation of full-scale performance, a major portion of the contract was devoted to the development and use of an extensive instrumental monitoring system. The monitoring system consisted of a multi-point automatic sampling and collection system with automatic introduction to multi-parameter, continuous analytical instrumentation. The complex nature of this system involved considerable time to assemble, perfect, and make operational.

The selection of the Back River Wastewater Treatment Plant at Baltimore for this study was based on the fact that it had two easily separable 10.0 mgd activated sludge systems, which amounted to only 10 percent of the total plant flow, permitting flexibility in operation. Some minor modifications were necessary to completely separate the two activated sludge systems. This likewise contributed to the necessary lag before the commencement of the full-time field portion of the study.

The original plan of project activities called for four months for the delivery of equipment, setup of laboratory and analytical systems, training of personnel, and the completion of the plant modifications. This was to be followed by a ten-month field study period for full-scale investigations. The actual sequence of project activities was as follows:

Time	Activity
Feb. 1969	Chemist and laboratory assistants on-site to begin training and set-up temporary laboratory.
Mar. 1969	Temporary laboratory completed and project engineer on-site.
Apr. 1969	Activated sludge plant modifications completed and Technicon autoanalyzers installed.
May 1969	Leakage between full-scale systems corrected and last of sampling and analytical equipment delivered.
June 1969	All monitoring systems made operational and full-scale formal experimental study initiated.
Dec. 1969	Termination of formal full-scale studies.
Jan. 1970	Data tabulation and equipment inventory for closure of temporary field laboratory completed.
Feb. 1970	Two weeks of final tests on metal concentrations and laboratory studies.

This was the extent of the field activities at Baltimore, and the remaining project activities for data analysis and report completion have been performed at ROY F. WESTON's West Chester, Pennsylvania Offices.

General Study Plan

The general approach used for the formal field experimental portion of this project was operation of one half of the activated sludge facilities (System No. 1) as a control at the normal conditions used at Back River. The second portion (System No. 2) of the activated sludge plant was used as the test system, with the desired variations in operaing conditions being imposed for periods of one to three weeks. The actual study plan on the test system during the formal experimental portion of this project is listed in Table 1. During the period indicated (6/23/69 to 12/22/69), the control system was operated and monitored except between 12/6/69 and 12/22/69, when the No. 1 aeration tank was taken out of service to permit the desired variations in aeration tank mixing configuration.

The operating conditions included in the formal full-scale study consisted of: baseline operation determination; low and cyclic dissolved oxygen levels in aeration tank; low and high levels of suspended solids in the aeration tank; low, high and diurnally-varied flow to the systems; and modifications of the conventional activated sludge operation to step aeration, contact stabilization, and toward complete mixing. This range of conditions included all the initially proposed studies with the exception of the substitution of mixing configuration tests for a phosphorus addition test and an organic carbon dilution test. Other studies originally discussed, such as varying the phosphorus-to-calcium ratio by lime addition, or reducing the aeration tank pH by the addition of acid, were not included in this study. The reason for this departure from the original study plan was the agreed-upon interest in variations in mixing configuration.

Description of Back River Plant

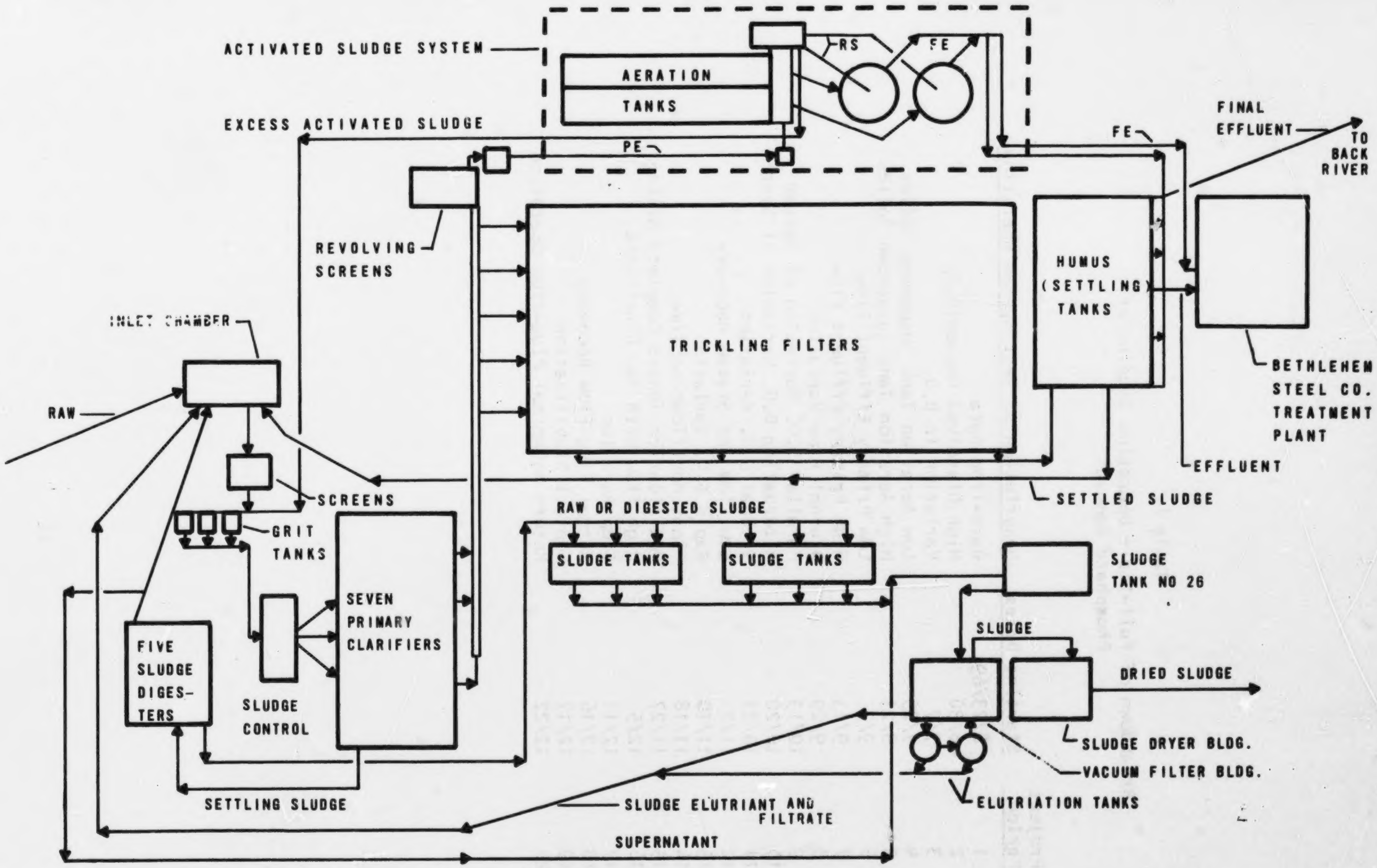
Before describing the necessary plant modifications at the activated sludge portion of the Back River Wastewater Treatment Plant, limited definition of the overall system is necessary. A block flow diagram of the overall Back River Wastewater Treatment Plant is shown in Figure 1. The plant currently treats approximately 170 mgd; secondary treatment is by trickling filter for 150 mgd and by activated sludge for the remaining 20 mgd. All excess secondary sludge is piped back to the plant inlet chamber ahead of the primary clarifiers. As a result, the activated sludge section of the treatment plant receives approximately 12 percent of the supernatant liquid associated with the waste activated sludge. Current sludge-handling practices at the Back River Wastewater Treatment Plant include the use of five heated anaerobic sludge digesters, which have a capacity (and are operated at that capacity) of half the current sludge production. The raw and digested sludge after storage is elutriated and polymer is added prior to vacuum filtering and drying. The principal liquid streams from the sludge-handling facilities returned to the plant inlet chamber are the elutriation water and the vacuum filtrate.

An expanded flow diagram of the activated sludge part of the plant is shown in Figure 2. The common primary effluent flows by gravity into the two 2.6-million gallon aeration tanks, with air applied through fixed diffuser plates of varying porosities to apply tapered aeration. At the overflows from the aeration tank, the mixed liquor flows to two 126-foot diameter circular final settling tanks with side wall depths of 13 feet each. The final secondary effluent from the center-feed, peripheral-overflow clarifiers flow to Bethlehem Steel for industrial

Table 1

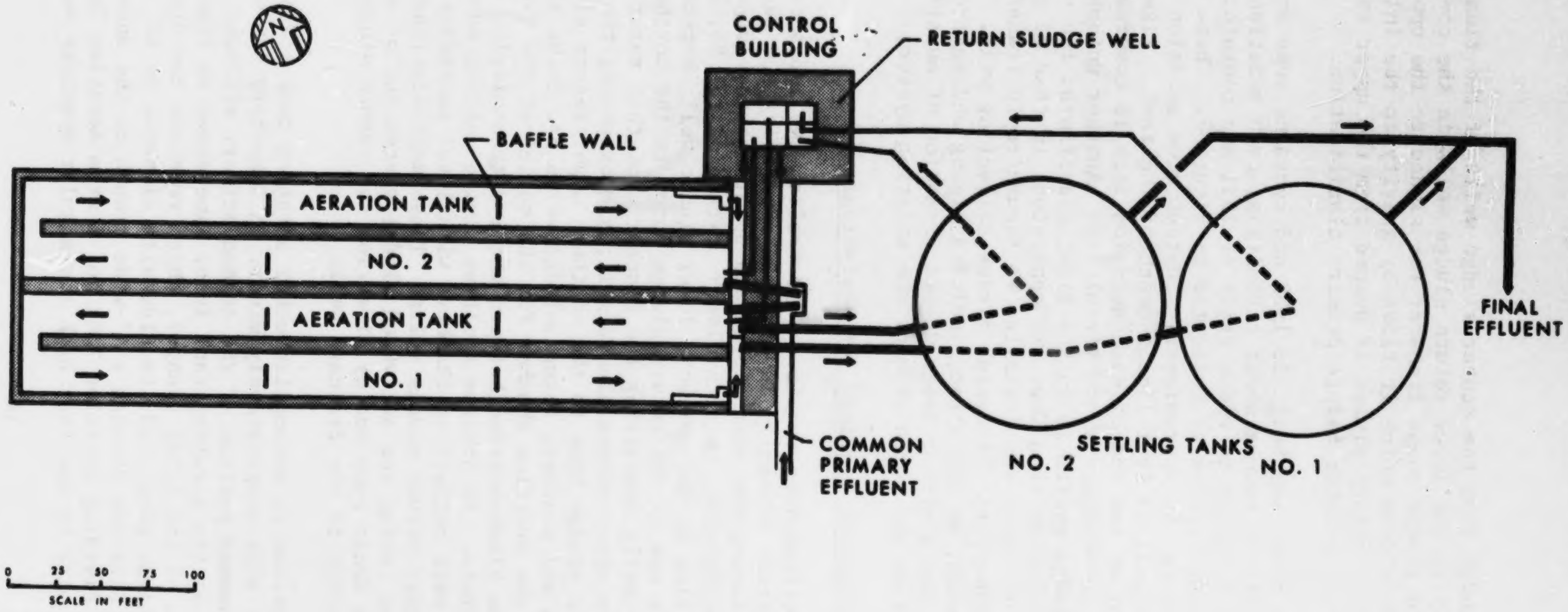
Breakdown of Full-Scale Operation Studies of Phosphate Removal

Project Period	Starting Dates	Description of Test System Operation
1	6/23/69	Base-line Data
2	6/30	High Dissolved Oxygen (D.O.)
3	7/7	Variation in D.O.
4	7/29	Low Aeration Tank Suspended Solids
5	8/23	High Aeration Tank Suspended Solids
6	9/3	Low Primary Effluent Flow
7	9/13	High Primary Effluent Flow
8	9/29	Diurnal Flow Variation
9	10/13	Parallel D.O. Variation of System
10	10/20	Alternating D.O. Variation of System
11	10/27	Gradual D.O. Variation
12	11/2	Low Flow and System Recovery
13	11/10	Rapid D.O. Variation
14	11/18	Plant Modification Time
15	11/27	Modification Toward Complete Mixing
16	12/5	High Flow with Two Clarifiers
17	12/11	Step Aeration
18	12/16	Normal Plug-Flow Recovery
19	12/17	Contact Stabilization
20	12/22	Return to Normal Plug-Flow Operation


ACTIVATED SLUDGE SYSTEM
AERATION TANKS
RS
FE
EXCESS ACTIVATED SLUDGE
PE
FE
FINAL EFFLUENT
TO BACK RIVER
REVOLVING SCREENS
INLET CHAMBER
RAW
TRICKLING FILTERS
HUMUS (SETTLING) TANKS
BETHLEHEM STEEL CO. TREATMENT PLANT
EFFLUENT
SETTLED SLUDGE
SCREENS
GRIT TANKS
RAW OR DIGESTED SLUDGE
SLUDGE TANKS
SLUDGE TANKS
SLUDGE TANK NO 26
SEVEN PRIMARY CLARIFIERS
FIVE SLUDGE DIGES- TERS
SLUDGE CONTROL
SLUDGE
DRIED SLUDGE
SLUDGE DRYER BLDG.
VACUUM FILTER BLDG.
ELUTRIATION TANKS
SETTLING SLUDGE
SLUDGE ELUTRIANT AND FILTRATE
SUPERNATANT

BACK RIVER WASTEWATER TREATMENT PLANT, BALTIMORE, MARYLAND

FIGURE 1


CONTROL BUILDING
RETURN SLUDGE WELL
BAFFLE WALL
AERATION TANK
NO. 2
AERATION TANK
NO. 1
FINAL EFFLUENT
COMMON PRIMARY EFFLUENT
SETTLING TANKS
NO. 2
NO. 1
N
0
25
50
75
100
SCALE IN FEET

BALTIMORE ACTIVATED SLUDGE WASTEWATER TREATMENT SYSTEM

FIGURE 2

water reuse. The sludge from the center sludge wells of the final clarifiers flow by gravity to the lower return sludge wells in the control building. Two return sludge pumps transfer the sludge to the upper wells in the control building from which it flows by gravity to the inlet of the aeration tanks. Excess return sludge is pumped from the upper return sludge well to the plant inlet chamber before primary clarification.

The activated sludge plant was built in 1939 and contains some unique features. In an effort to reduce short circuiting, each aeration tank was constructed with a length to width ratio of 25:1 and contains four intermediate transverse baffles as indicated in Figure 2. These baffles are 12 feet wide in the approximately 30-foot wide aeration tank width and extend the full 15 feet liquid depth of the tank. Likewise, the turn-around point at the end of each aeration tank is compressed to a 10' x 10' port to minimize short circuiting. Another unique feature of this activated sludge system is in the final clarifiers; the plow-type sludge collection mechanism is a four-arm apparatuus instead of the common two-arm collector. This was installed to insure rapid transfer of sludge from the periphery to the center sludge collecting well. The activated sludge system, as installed, included piping and control building facilities for a mirror image 20-mgd expansion of aeration tanks and clarifiers on the north side of the existing system.

Modifications Required for Test Program

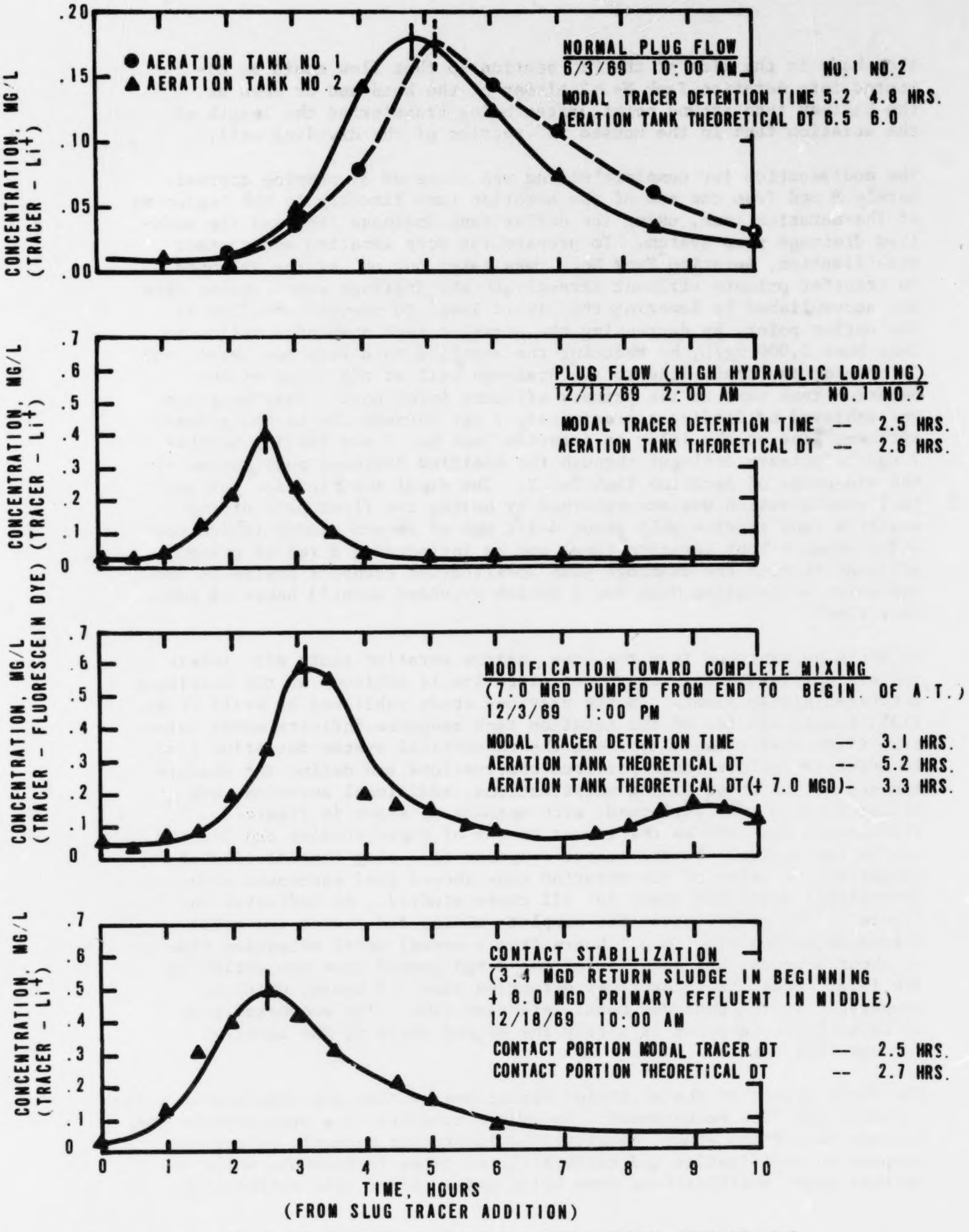
The actual plant modifications required to establish two independent activated sludge systems primarily involved in separating the two return sludge streams by placing the north lower and upper return sludge well system in use. Specifically, this involved: extending the No. 1 clarifier return sludge line to the northern lower sludge well; extending the suction line for one of the return sludge pumps to the northern lower return sludge well; connecting the discharge of that return sludge pump to the northern upper return sludge well; and extending the No. 1 aeration tank return sludge line to the northern upper return sludge well. The northern and southern return sludge wells had to be block-boarded apart, and the overflow chamber for the outlet of the two aeration tanks had to be block-boarded between the two transmission lines to the final clarifiers. To achieve positive sludge-wasting measurements, two V-notch weir collection chambers with level-recorders were installed in the upper return sludge wells. These modifications were accomplished without taking the activated sludge system out of service, by using the system drain pump and by diverting the return sludge from the clarifiers directly to the drainage well.

The modifications needed to accomplish other aeration tank mixing configurations were also comparatively minor. A temporary dam was placed across the unused portion of the common primary effluent channel just north of the aeration tank inlet line shown on Figure 2. This unused portion of the inlet channel, which receives the discharge from the 8-mgd drainage pump, had its sidewalls elevated by 18" so that flow could be directed through a 4'-wide trough to the unused center "Y" section dividing Aeration Tank No. 1 from Aeration Tank No. 2. Three-foot wide by one foot high rectangular openings were then made in the side of the "Y" section so that flow could be directed into Aeration Tank No. 2 either at the head end or down at the halfway turn around point, after being transferred the length of the aeration tank in the unused "Y" section of the dividing wall.

The modification for complete mixing was achieved by pumping approximately 8 mgd from the end of the aeration tank directly to the beginning of the aeration tank, using the outlet tank drainage line and the modified drainage pump system. To prepare for step aeration and contact stabilization, Aeration Tank No. 1 was taken out of service and used to transfer primary effluent directly to the drainage pump system; this was accomplished by lowering the liquid level to prevent overflow at the outlet point, by decreasing the aeration tank suspended solids to less than 1,000 mg/L, by reducing the aeration to a very low level, and by opening the drain line to the drainage well at the inlet of the aeration tank next to the primary effluent inlet port. Step aeration was achieved by feeding approximately 7 mgd through the normal primary effluent line at the inlet to Aeration Tank No. 2 and feeding another 7 mgd of primary effluent through the modified drainage pump system to the mid-point of Aeration Tank No. 2. The final modification for contact stabilization was accomplished by having the first half of the aeration tank receive only about 4-1/2 mgd of return sludge (which provided about 6-hour aeration time) and by introducing 8 mgd of primary effluent through the drainage pump modification transfer system at the mid-point of Aeration Tank No. 2 (which provided about 3 hours of contact time).

As would be expected from the long, narrow aeration tanks with intermediate baffles, a high degree of plug flow is achieved at the Baltimore activated sludge plant. In the previous study published by Scalf et al. (13), tracer studies of the aeration tank response indicate modal detention times that closely approach the theoretical system detention time. In order to confirm these previous observations and define the changes imposed by the above mixing modifications, additional aeration-tank tracer studies were performed, with results as shown in Figure 3. Fluorescein was used as the tracer in one of these studies and lithium ion in the others. Outlet tracer response to a slug introduction of tracer at the inlet of the aeration tank showed good agreement with theoretical detention times for all cases studied. As indicated in Figure 3, the modification for complete mixing did reduce the modal tracer detention time to 3.1 hours from a normal modal detention time of about 5 hours, but addition of the 7 mgd pumped from the outlet to the inlet makes the theoretical detention time 3.3 hours, which is comparable to the observed modal detention time. The secondary peak in this tracer response is merely the second cycle of the material through this system.

The final aspect of the activated sludge system that was involved in modification was flow measurement. To assure accurate flow measurements and records during the study, considerable instrument mechanic effort was devoted to modification and calibration of these instruments while the initial plant modifications were being made. After this calibration



FULL-SCALE AERATION TANK TRACER STUDIES

FIGURE 3

effort had been completed and just before the initiation of the formal study, a series of lithium-dilution flow measurements were performed to check the primary effluent and return-sludge Venturi flow-measuring and recording instruments. The lithium data showed that the flow meter accuracy was satisfactory in all cases, and the actual results are tabulated in Table A-1.

Description of Sampling and Analytical Systems

For this project, a special monitoring system was designed and installed for continuous operation with automatic hourly retrieval at as many as eleven sample points located at various parts of the treatment plant. The eleven permanent sampling points included: the common primary effluent to the activated sludge system; the two final clarifier overflows, the two return sludge streams (collected for each system at the two upper return sludge wells); and inlet, middle, and outlet portions of each of the two aeration tanks. All samples were pumped to a central location and processed by an automatic switching system, which collected samples for daily composite analyses and sequentially introduced samples and standards to continuous analytical instrumentation.

The parameters measured and recorded on a continuous basis were: flow, pH, turbidity, total dissolved carbon, dissolved COD, nitrite-nitrate, ammonia, ortho-phosphate, and on a less frequent basis total phosphorus and total Kjeldahl nitrogen. Measurements made on the daily composited samples from the automatic refrigerated collection system included: suspended solids, total phosphorus, total Kjeldahl nitrogen, and BOD. Specific metal ions were routinely measured on weekly composite samples and on selected grab samples. Since this sampling and analytical system was especially designed and developed for this project, a detailed description of the monitoring system is included as Appendix B.

The ortho-phosphate, ammonia nitrogen, combined nitrite-nitrate, and COD were measured by standard Technicon auto-analyzer methods. The total phosphorus and total Kjeldahl nitrogen were measured by a specially-developed simultaneous Technicon auto-analyzer system, which used a rigorous digestion procedure of perchloric acid and vanadium pentoxide. The Union Carbide total carbon analyzer had to be modified to determine on an interim manual basis the total inorganic carbon. These methods and equipment are also summarized in Appendix B. Metal analysis for calcium, magnesium, iron, aluminum, zinc, copper, and sodium were determined by atomic absorption methods. Where total metal ion contact was desired, a digestion procedure using a mixture of hot sulfuric and nitric acid was used; in this procedure, special consideration had to be given to sulfate correction for determination of calcium. The BOD procedure was modified in selected test samples by adding thiourea to supress nitrification in an effort to measure long-term carbonaceous BOD. All standard manual laboratory measurements were made in accordance with Standard Methods for the Examination of Water and Wastewater, 12th edition (14). Suspended solids measurements performed (six times a day on samples from the outlet of the two aeration tanks) by the activated sludge operating staff for normal control purposes have been used in this report.

The experimental nature and magnitude of the monitoring system imposed certain constraints on its operation. The mode of operation of the continuous automatic sampling and analytical system was a four-day week (from 10:00 a.m. Monday morning continuously through 10:00 a.m. Friday morning). This schedule was selected because of project manpower limitations for system maintenance and because of the requirements for tabulation of analog chart outputs. During the first 16 weeks of the formal research study, the sampling system was operated on all eleven sampling points; however, sample introduction to the Technicon and Union Carbide analytical systems was on a manual basis after certain necessary sample preparation measures (involving suspended solids removal) had been performed. During the final ten weeks of the study, the sampling system was operated on three sampling points (the common primary effluent and the two secondary effluent sampling points). With the reduced level of suspended solids, the Technicon and Union Carbide systems were operated on an automatic basis in conjunction with the other instrumentation and sample collection activities. This terminal mode of operation provided the excellent operating aid of knowledge of phosphate and total carbon performance approximately 10 minutes after respective position sampling times.

Laboratory-Scale Studies

Although most of the effort in this research project was devoted to the full-scale research study, limited laboratory-scale studies were also conducted. These included: assessment of the effects of the level of dissolved oxygen during aeration; the effect of various mixing configurations on phosphate removal; and limited batch studies on other aspects affecting phosphate removal. The batch studies were performed in 5-liter aeration vessels, and the continuous laboratory-scale studies were performed in a system containing a 12 liter aeration volume and a 4.5-liter secondary settling tank. A modification using the Technicon sampler permitted the hourly sampling of the laboratory-scale activated sludge system.

Data Tabulation

For feasible retrieval, the automatic monitoring data were tabulated and transferred to computer cards which located the data by date, time, sample point, and parameters. The data placed on the computer cards included flow, dissolved oxygen, pH, COD, total carbon, ortho-phosphate, ammonia nitrogen, and combined nitrite-nitrate nitrogen. The formal project data occupied approximately 50,000 computer cards, and a complete computer print-out grouped in weeks of the formal research study period is transmitted as a master data set volume. Additional computer-handling operations that have been performed on the data have been limited to meaningful weeks of data and have consisted of ranking, producing probability of occurrence plots, and extending the data to pounds/day. The significance of overall statistical analysis of the data is limited due to gradual trends in the activated sludge system and the long response time to variables artificially imposed on the activated sludge system. Therefore, considerable attention has been placed on chronological plotting of the full-scale monitoring data.

SECTION III

PRESENTATION OF EXPERIMENTAL RESULTS

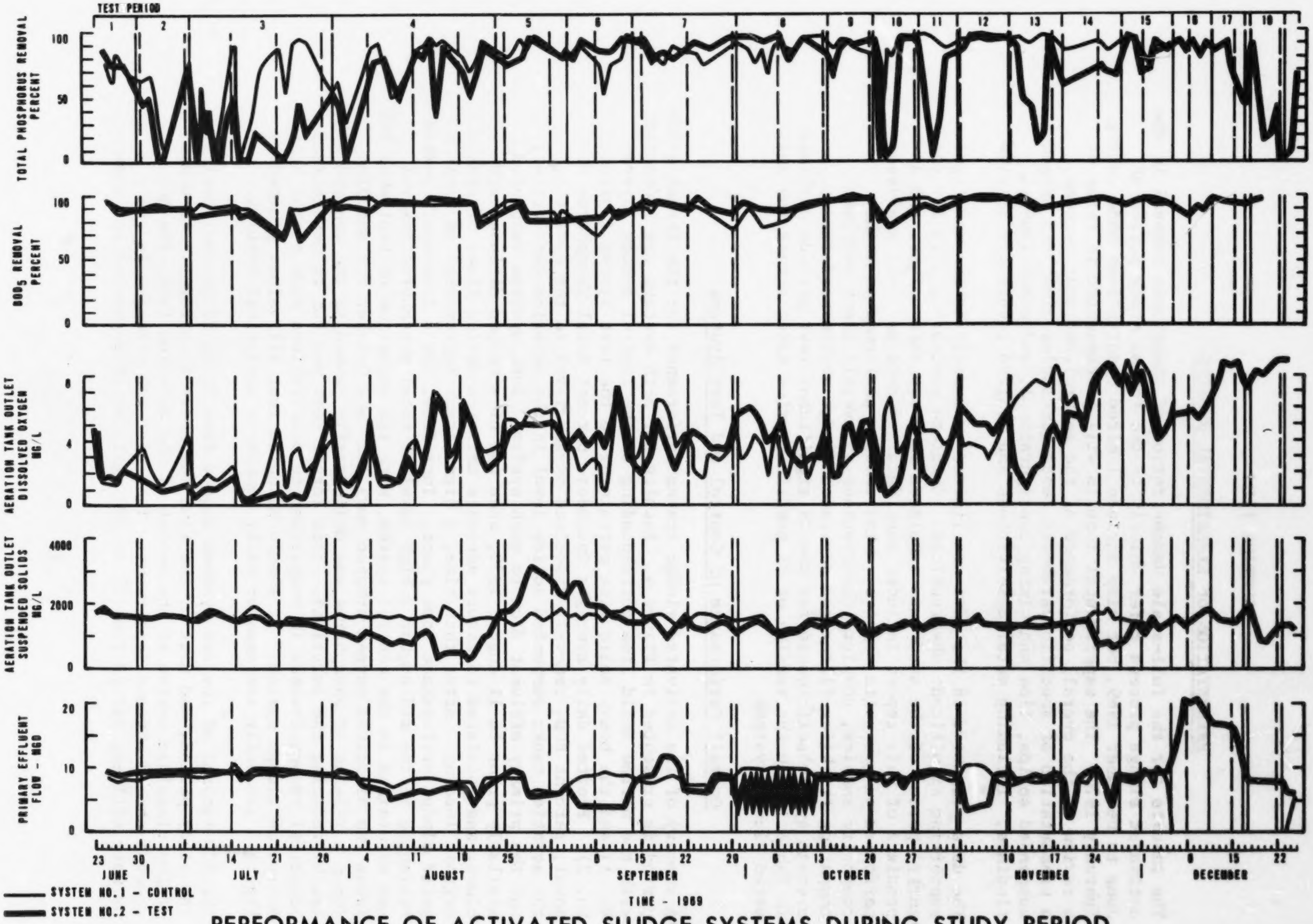
The results for the full-scale demonstration of phosphorus removal in the activated sludge process refer chiefly to the formal study period of June to December 1969, but also include limited observations made during February 1970. The experimental results will be presented in terms of a review of the overall performance of the control and test systems, a presentation of specific parameter tests (including dissolved oxygen, suspended solids, flow and mixing configuration), and other general findings, including metal observations and limited laboratory results.

The data presented in the text are limited to summary tables and figures supporting significant observations. Complete monitoring data for the entire period of the study are tabulated in a separate volume, and Appendix A of this report includes such detailed data as: all analyses performed on composite samples, metal results performed on weekly composite samples, complete observations on overall plant samples comparing trickling filter and activated sludge system performance, average system performance for the 19 significant test periods outlined in Table 1, and the results of 21 profile studies taken across the activated sludge systems.

Overall Performance of Control and Test Systems

A summary of the activated sludge system performance for the formal study period is presented in Figure 4. Results for both systems are indicated, with the narrow solid line corresponding to the control system (System No. 1) and the heavy solid line pertaining to the test system (System No. 2). Plotted daily averages include: percent total phosphorus removal; percent BOD_5 removal; dissolved oxygen level in the outlet of the aeration tank; suspended solids level in the aeration tank outlet; and the primary effluent flow to each system. Both systems responded similarly prior to 11 August 1970, when use of a second diffused air blower was initiated to assure adequate aeration during times of peak organic loading. After that time, a significant improvement in activated sludge performance took place. Therefore, for a four-month period beginning in the mid-August a high level of total phosphorus removal was maintained in the control system, with the exception of September 9th (when the dissolved oxygen dropped very low) and October 7th and 21st (when a release of phosphorus was deliberately caused in the control system by reducing the aeration). This latter test was run to demonstrate identical responsiveness in comparison to observations made on the test activated sludge system. It should be noted that all values plotted on Figure 4 are daily averages or daily composite analytical results.

The BOD removal of the two systems ranged from 65 to 97 percent during the study period, and most of the time was above 85 percent. At times of low dissolved oxygen at the outlet of the aeration tank, the BOD removal showed obvious impairment. The inlet BOD strength in the primary effluent varied from 57 to 380 mg/L, which accounted for some



PERFORMANCE OF ACTIVATED SLUDGE SYSTEMS DURING STUDY PERIOD
FIGURE 4

of the variation observed in percent removal. The chronological plot of the aeration tank outlet dissolved oxygen shows the difficult control problems that were experienced during the first six weeks of the study. During the initial D.O. evaluation tests (test periods 2 and 3), the desired D.O. difference between the test system (No. 2) and the control system (No. 1) was not achieved due to limited blower capacity. However, after installation of the second blower, the D.O. variation studies performed during test periods 9, 10, 11, and 13 (as shown on Figure 4) indicated that significant differences in D.O. were achieved on the two systems; the corresponding effects on phosphate removal can be seen.

The overall aeration tank suspended solids operation during the study period consisted of maintaining the control system at approximately 2,000 mg/L suspended solids and holding the test system suspended solids levels below 1,000 mg/L during test period 4 and above 3,500 mg/L in test period 5.

Only the order-of-magnitude changes in flow can be seen on Figure 4. The two specific low-flow studies in the test activated sludge were made during test periods 6 and 12; the diurnal flow variation study was during test period 8; the successful high-flow study was conducted during period 16, with an unsuccessful attempt during period 7. This earlier high-flow test was not successful because severe bulking occurred in both activated sludge systems during the week of 15-19 September 1969, and the primary effluent flow to both systems was reduced in an effort to maintain reasonable effluent quality and to correct the bulking situation. A similar bulking situation occurred during the week of 25-29 August 1969, and the resulting imposed reduction in primary effluent flow can be seen on Figure 4.

The mixing configuration studies took place during test period 15 for complete mixing, 17 for step aeration, and 19 for contact stabilization. The corrective effects on activated sludge phosphate removal caused by returning to plug flow on periods 18 and 20 are also seen on Figure 4.

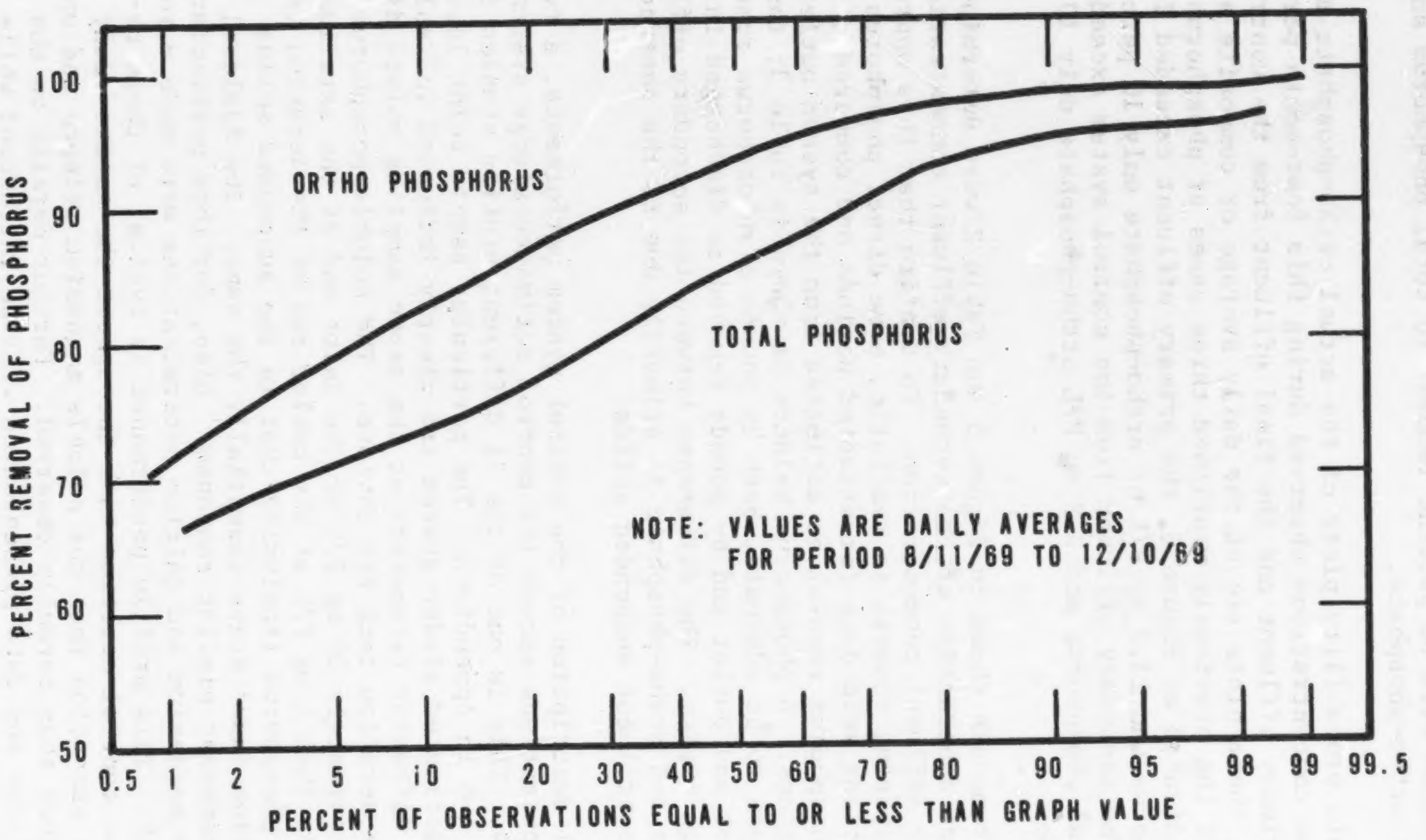
The overall average performance of both the control and test systems is presented in Table 2. These averages are of reduced significance because of the wide range of conditions in the activated sludge system during the study period. In order to obtain a reasonable estimate of the full-scale activated sludge phosphorus removal in the control system at Baltimore, performance data for that portion of the study period after the initiation of the use of the second blower were averaged. Therefore, average control system performance for test periods 5 through 15 is also shown on Table 2.

To clarify the presentation of the phosphate removal performance of the control activated sludge system during this four-month period, a probability plot is presented in Figure 5. This was prepared by taking the observed daily performance and ranking and plotting the values. The three observed low values of phosphate removal (on September 9th, October 7th, and October 21st) were not included in the probability plot because operation was not normal on those days, but was deliberately imposed on

Table 2

Average Project Operation and Performance Conditions

Parameters	Performance Conditions	System No. 1 6/23-12/4/69	System No. 2 6/23-12/21/69	System No. 1 8/25-12/4/69
Flow	Primary Effluent, mgd	8.9	9.1	9.1
	Return Sludge, mgd	2.0	2.5	2.1
	Sludge Wasting, mgd	0.18	0.20	0.20
P	P.E., Total Phosphorus, mgP/L	11.3	11.3	11.4
	P.E., Ortho Phosphate, mgP/L	9.3	9.2	9.7
	Removal of Total Phosphorus, %	75	63	82
SS	P.E., Suspended Solids, mg/L	148	139	156
	Secondary Effluent SS, mg/L	11	12	12
	Aeration Tank SS, mg/L	2,090	2,030	2,060
	Aeration Tank VSS/SS, %	73	74	73
C	P.E. Total Carbon, mg/L	168	160	153
	Removal of Total Carbon, %	58	57	60
BOD_5	P.E. - BOD_5, mg/L	177	178	169
	Removal of BOD_5, %	90	90	91
	BOD_5 Loading, lb./day/lb. SS	0.29	0.32	0.29
	Production lbs. SS wasted/lb. BOD_5	1.14	1.10	1.24
N	P.E. - Ammonia N, mg/L	23.6	23.8	26.4
	P.E. - Kjeldahl N, mg/L	27.8	28.2	30.0
	Removal of Kjeldahl N, %	40	39	42
	S.E. Nitrate + Nitrite N, mg/L	0.75	0.70	0.93
pH	Primary Effluent	6.4	6.3	6.4
	Secondary Effluent	7.0	7.0	7.0
	Air Supplied SCFM/gal.	1.42	1.69	1.61



CONTROL ACTIVATED SLUDGE SYSTEM
PHOSPHORUS REMOVAL VARIABILITY

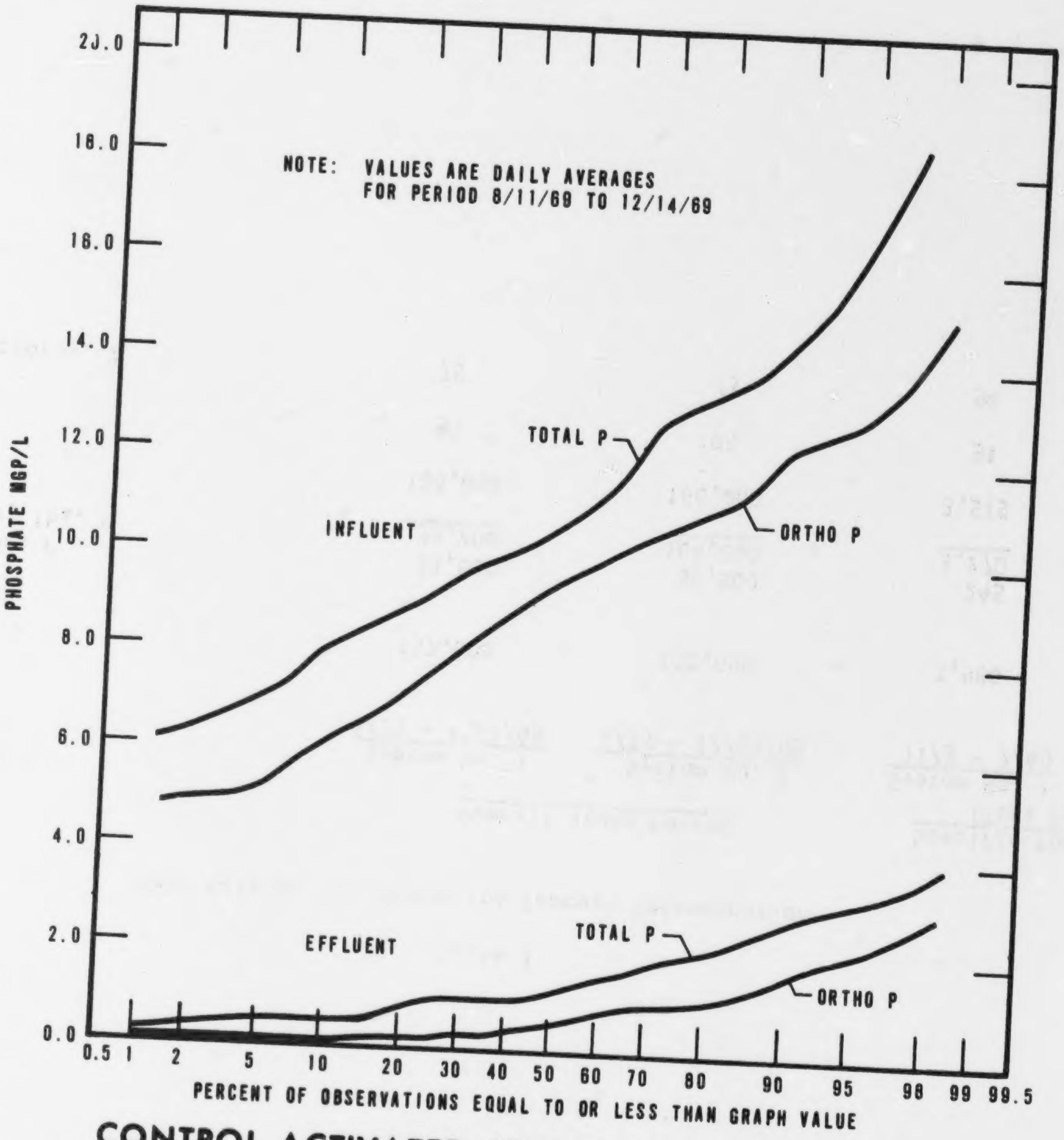
FIGURE 5

the control system for test purposes. More than 60 values went into the composition of the probability plot, and they indicated that the total phosphorus removal be less than 73 percent or the ortho-phosphate removal less than 83 percent only 10 percent of the time. The 50 percent probability-of-occurrence values were 86 percent removal to total phosphorus and 93 percent removal of ortho-phosphate.

Figure 6 presents probability plots of the actual ortho-phosphate and total phosphorus concentrations observed during this four-month period for both the primary effluent and the final effluent from the control system. Again, these plots are of the daily average or composite sample results and omit the previously mentioned three cases of phosphorus release. As indicated on Figure 6, the primary effluent exceeded 15 mg P/L of total phosphorus and 13.3 mg P/L of ortho-phosphate only 10 percent of the time. The secondary effluent from the control system exceeded 3 mg P/L of total phosphorus and 2.2 mg P/L ortho-phosphate only 10 percent of the time.

The phosphorus removals shown in Figure 5 and Table 2 were determined on a basis of direct subtraction of the secondary effluent concentration from the primary effluent concentration. To confirm that this approximation of the phosphorus removal is realistic, some direct phosphorus balance computations were done for selected periods and compared with the indicated phosphorus removal as estimated from the system outlet and inlet concentrations. A phosphorus balance is shown in Table 3; the comparison appears to be adequate, both by pounds of phosphorus removed between the inlet and outlet and by pounds removed as discharged in the return sludge system. The difference between the secondary effluent total phosphorus and ortho-phosphate is primarily due to the phosphorus contained in the effluent suspended solids.

As an additional description of the control system performance, a typical profile of concentrations across the control activated sludge system is shown in Table 4. This is one of the 21 different profile studies included in Table A-6 in Appendix A. The particular sample point locations throughout the activated sludge system are clearly indicated in Table 4. The changes and different parameters at the seven sampling points distributed across the aeration tank are obvious. The soluble phosphorus ranges from approximately 30 mg P/L at the inlet end of the aeration tank down to less than 1 mg P/L at the outlet end of the aeration tank, while the total phosphorus (including that in the suspended solids across the aeration tank) stays essentially the same. The Kjeldahl nitrogen shows a somewhat similar response. Also, for this particular profile, soluble magnesium and calcium determinations were made across the aeration tank. This profile performance is typical of those observed across the control aeration tank throughout the entire study period, with the exception that the soluble magnesium release and uptake are slightly higher than normally observed. Further details on the profile observations and data presentation will be introduced while presenting the individual parameter studies.



CONTROL ACTIVATED SLUDGE SYSTEM VARIABILITY
IN INFLUENT AND EFFLUENT PHOSPHORUS CONCENTRATIONS
FIGURE 6

Table 3

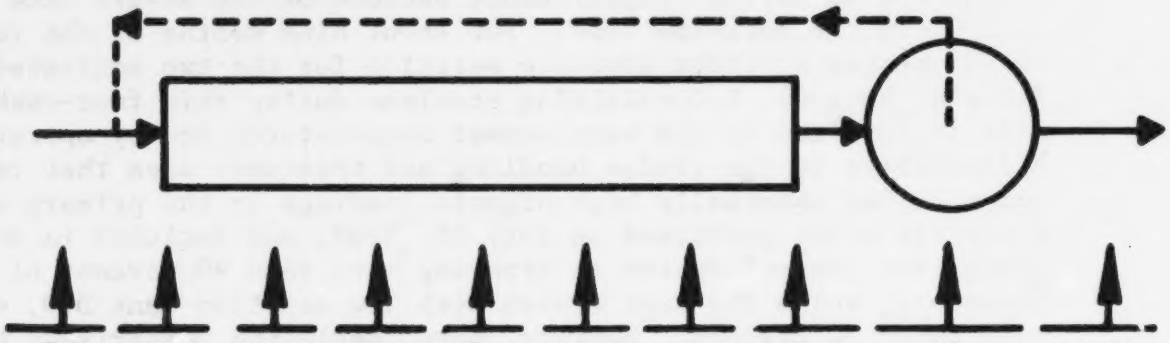
Mass Balance for Phosphorus Removal Determination

	Overall Study Period		Specific Four-Day Period (Test Period 12)	
	System No. 1 6/23 - 12/4/69	System No. 2 6/23 - 12/21/69	System No. 1 11/3 - 7/69	System No. 2 11/3 - 7/69
Incoming:				
Primary Effluent, lbs. P	137,000	152,000	3,900	1,960
Accounted for:				
Secondary Effluent, lbs. P	33,600	55,800	245	123
Waste Activated Sludge, lbs. P	95,200	104,200	3,270	1,805
Total	128,000	160,000	3,515	1,928
Precent Accounted for	94	105	91	99
Overall Removal of Phosphorus, % (inlet to effluent)	75	73	94	94

Table 4

Typical Profile Analytical Results[1]

Activated Sludge System No. 1



Sampling Positions[2]

Normal Control System 12/3/69 - 4:00 p.m., MLSS = 1850 mg/L, P/SS = 5.4 percent

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
D.O., mg/L	-	0.1	0.1	0.3	1.0	3.6	4.6	5.2	-	1.2
pH	6.6	6.6	6.7	6.8	6.8	6.8	6.8	6.8	6.5	6.8
BOD_5, mg/L	170	-	-	-	-	-	-	-	-	10
Sol. COD, mg/L	215	75	70	55	50	40	35	30	90	45
Sol. TOC, mg/L	110	55	50	40	35	30	30	25	55	35
Ortho PO_4, mg P/L	8.7	30.2	24.4	16.3	5.5	1.0	0.5	0.3	46.4	0.3
Sol. Tot. P, mg P/L	9.7	33.0	27.0	18.8	6.2	1.4	0.8	0.7	>50	-
Tot. P, mg P/L	-	98	97	98	98	100	98	102	520	-
Sol. Tot. KN, mg/L	-	29.2	28.6	26.2	21.6	18.8	16.8	16.0	27.0	-
Tot. KN, mg/L	36.0	150	156	154	152	156	148	152	516	-
Sol. Mg, mg/L	-	17.6	16.8	14.0	11.0	8.8	8.0	7.6	17.0	-
Sol. Ca, mg/L	-	26.5	27.8	26.5	25.0	30.0	24.0	25.0	30.0	-

[1] All other profile results will be presented in a similar manner.

[2] Legend:

PE - Primary Effluent.
AT-1 to A-6 - Aeration tank sampling points located at respective positions along the length of the aeration tank.
RS - Return Sludge.
SE - Secondary Effluent.

Specific Parameter Studies

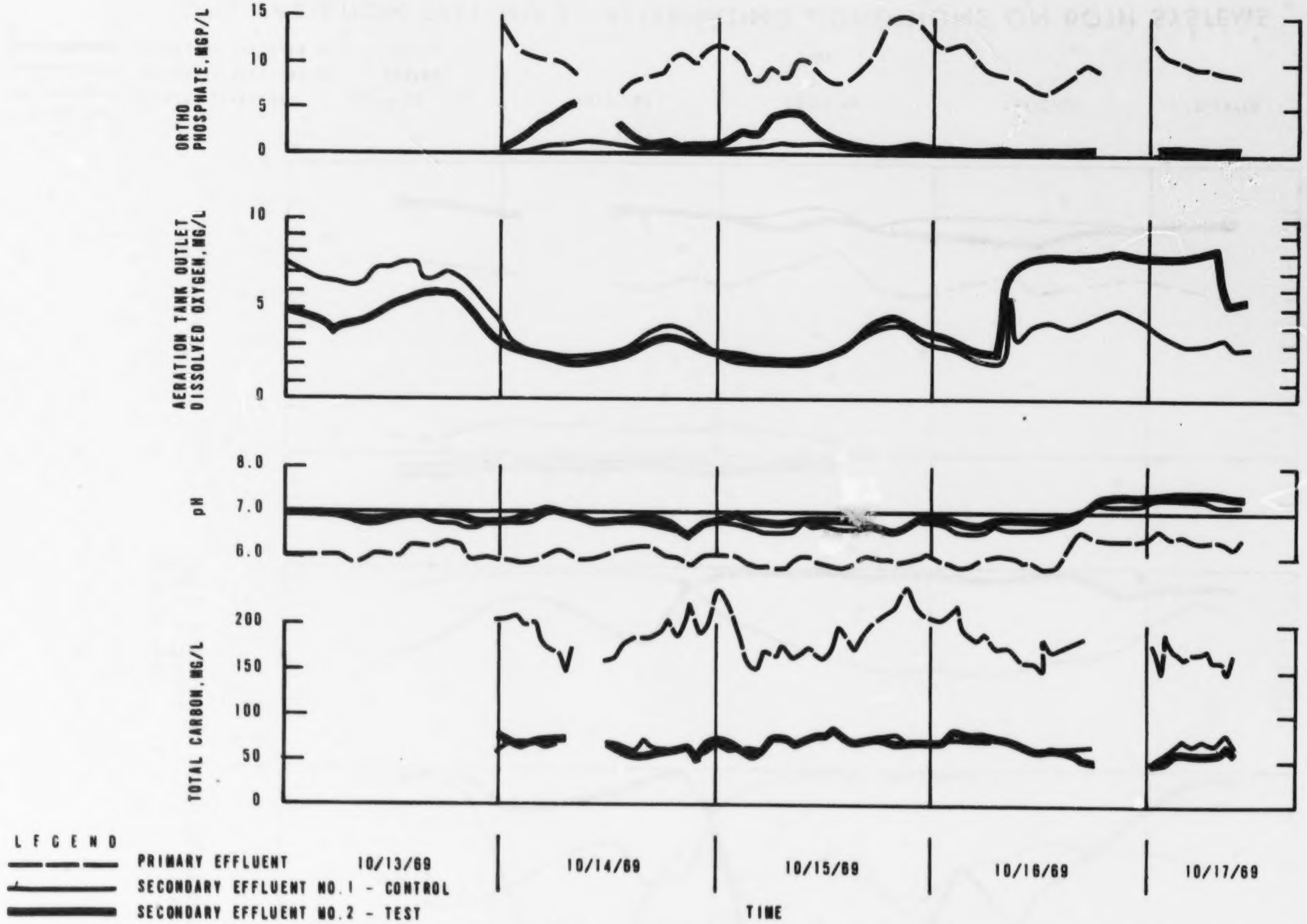
Dissolved Oxygen Variation

A considerable portion of this study (test periods 2, 3, 9, 10, 11, and 13 - eight weeks out of the 26-week total) was devoted to an examination of the full-scale effect of dissolved oxygen variation in the aeration tanks. The first four weeks of dissolved oxygen variation observations that took place prior to the initiation of the use of the second aeration blower are of reduced significance because of the severe lack of control of D.O. in the aeration tank. For about nine months of the year, operation of one blower provides adequate aeration for the two activated sludge systems; however, D.O.-limiting problems during this four-week period were intensified by the warm summer temperatures and by operating difficulties in the sludge handling and treatment area that resulted in uncontrolled abnormally high organic loadings in the primary effluent. A profile study performed on July 25, 1969, and included in Appendix A, showed the control system as removing more than 90 percent of the soluble phosphate, while the test system with low aeration tank D.O. was removing only about 20 percent. However, more conclusive comparisons between the high dissolved oxygen and low dissolved oxygen aeration tank conditions were observed and will be reported for subsequent dissolved oxygen studies.

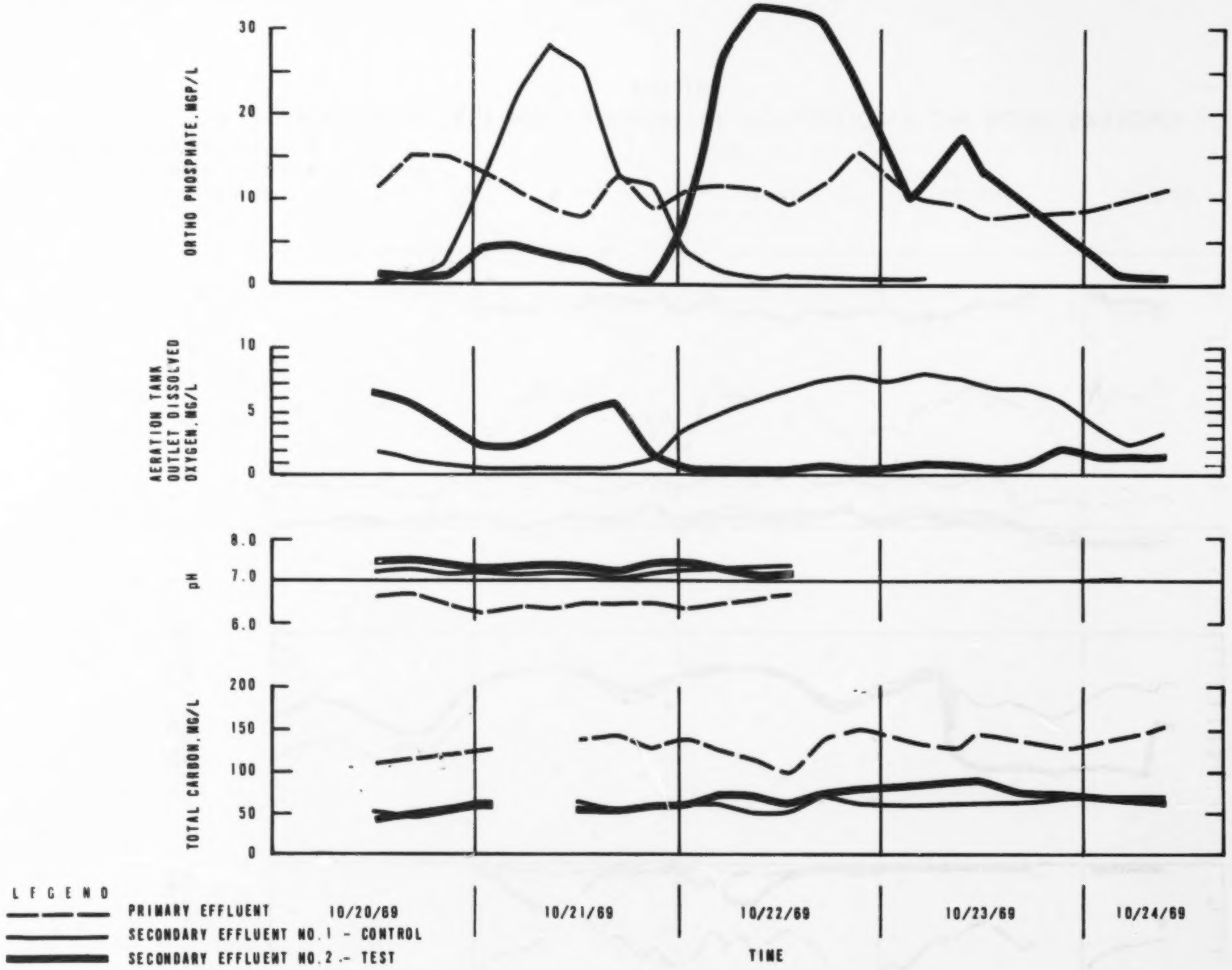
D.O. Response of Both Full-Scale Systems

The remaining four weeks of D.O. variation studies took place when the analytical monitoring system was operated with a higher degree of refinement and a more definitive comparison of the two system responses could be made. A chronological plot of the activated sludge system performance for the first of these later D.O. variation studies with parallel conditions on both systems is shown in Figure 7. The plotted lines represent hourly observations of the four parameters of ortho-phosphate, aeration tank outlet dissolved oxygen, pH, and total carbon. Some brief instrument outage time is indicated by the gaps in the plots. The intent of this study was to lower the outlet aeration tank dissolved oxygen levels gradually until a phosphorus release occurred. The dissolved oxygen levels were about equal in both systems reaching a minimum of approximately 2.0 mg/L, at which condition limited phosphorus release were caused in both secondary effluents, which were higher in No. 2 than No. 1. The low D.O. level attained in this one-week study of parallel conditions in both test and control activated sludge systems was not severe enough to stimulate a large release of phosphorus. Also, pH data in Figure 7 indicated a distinct shift in primary effluent pH on 10/16/69 and a subsequent shift in a secondary effluent pH approximately three hours later.

Figure 8 is a plot of the one-week D.O. variation Test No. 2, which involved alternating conditions on both the activated sludge systems and substantially lower aeration tank dissolved oxygen levels. The results are presented in a similar manner to those of Figure 7. The low D.O. conditions were first imposed on the control system, showing peak release condition of about 28 mg P/L of ortho-phosphate with a primary effluent average concentration of approximately 10 mg P/L. This was



D O VARIATION TEST NO.1 - PARALLEL CONDITIONS ON BOTH SYSTEMS
FIGURE 7



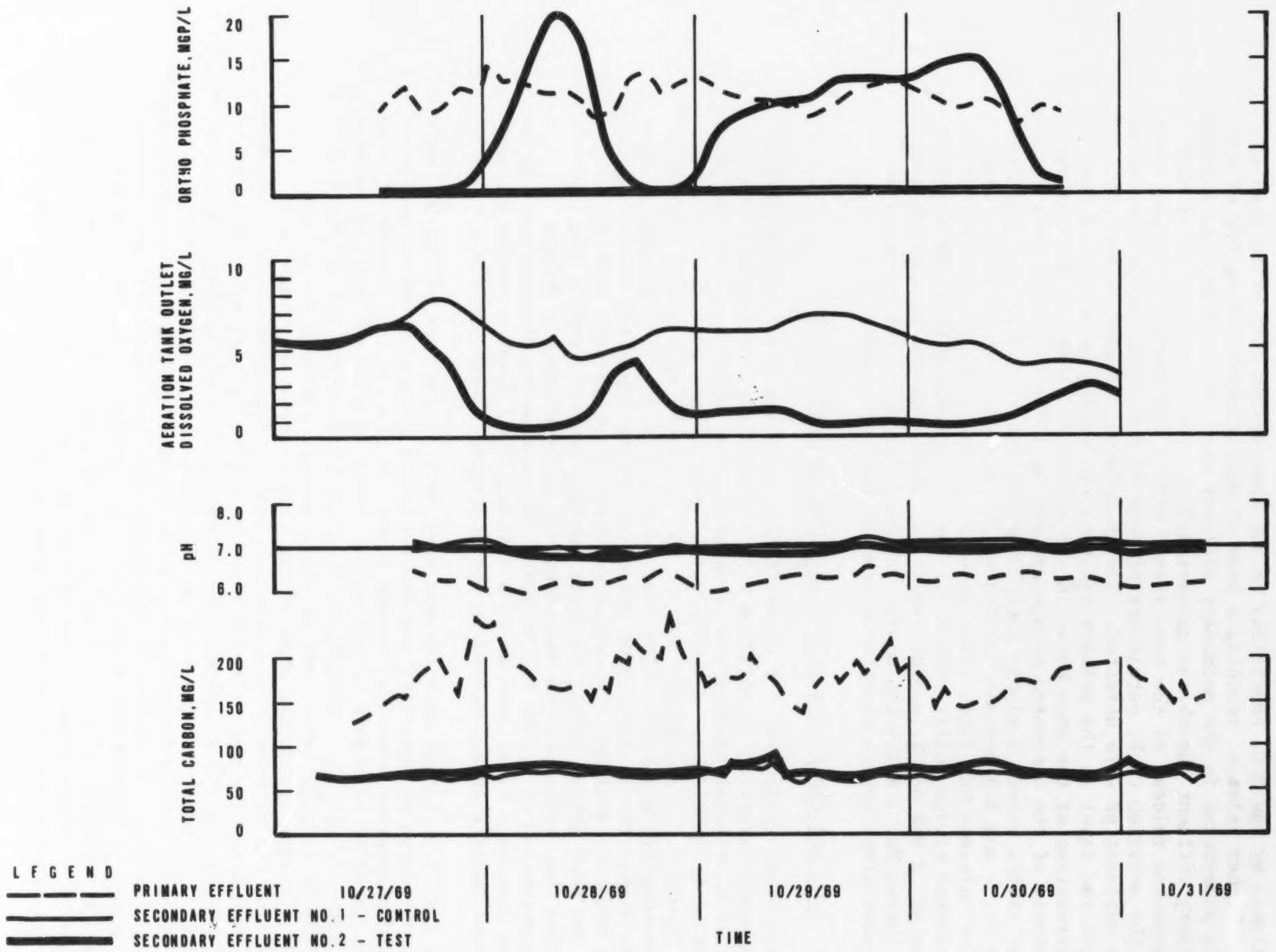
D O VARIATION TEST NO.2 - ALTERNATING CONDITIONS ON BOTH SYSTEMS
FIGURE 8

followed by low D.O. conditions on the test system that stimulated an even higher release, reaching a peak of approximately 33 mg P/L of soluble phosphorus in the secondary effluent with little change in incoming primary effluent phosphorus concentration. During the period of high phosphorus release of the test system with a low dissolved oxygen level in the aeration tank, derogatory effects on the total carbon removal and the effluent pH were detected. The phosphorus released in the effluent above the level in the primary effluent can easily be accounted for by observations of the phosphorus in the activated sludge in the systems. Analysis of the activated sludge systems on 10/17/69 before this particular study, showed a sludge phosphorus content of 5.3 percent for System No. 1 and 5.9 percent for System No. 2. Then, on 10/23/69, after major releases had taken place on both systems, similar analysis of the activated sludge solids showed 3.1 and 2.2 percent phosphorus for Systems No. 1 and No. 2, respectively. At this time the phosphorus content in System No. 1 activated sludge was building up to the normal 4 to 5 percent since system phosphorus removal had recovered.

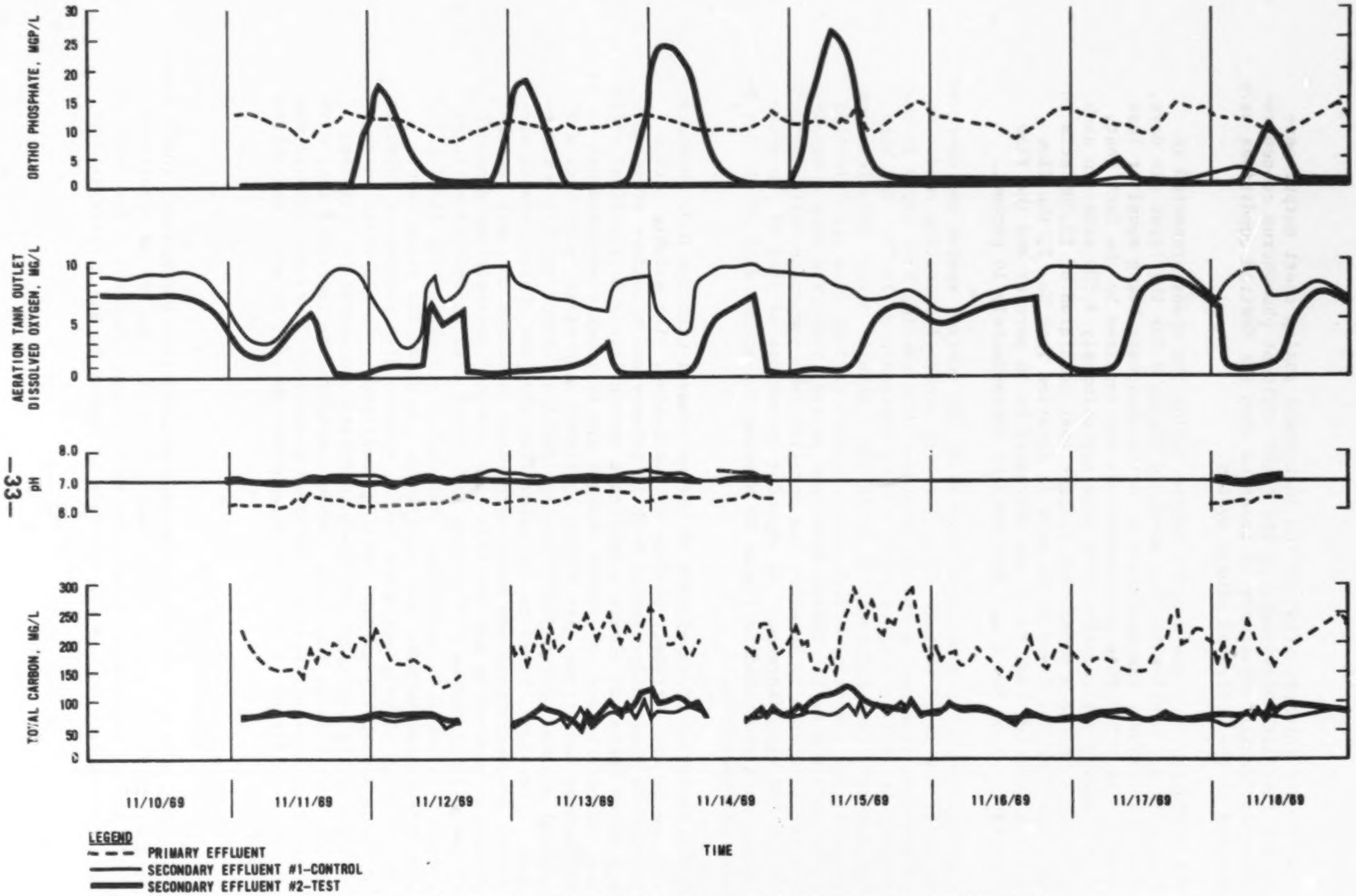
D.O. and Phosphorus Release Studies on Test System

During test period 11, a D.O. variation study was performed involving a gradual variation in aeration tank outlet dissolved oxygen level to see if a critical value could be determined at which a system phosphorus release is initiated. A chronological plot of the results is presented in Figure 9. A phosphorus release was initiated in the test system approximately six hours after the reduction of aeration in that system, even though the aeration tank dissolved oxygen was still above 2 mg/L in its downward decline. Two major releases of phosphorus took place in the test system during the test period; however, during the same period the control system maintained an ortho-phosphate outlet concentration of 0.3 mg P/L or less. No conclusive observations can be made from this brief test as to a critical D.O. level at which a phosphorus release is stimulated in the activated sludge process.

The last D.O. variation study was performed during test period 13, with the objective of observing how the activated sludge system responded to rapid changes in dissolved oxygen level. A plot of the results of this test is shown in Figure 10 and is presented in a format similar to that of previous studies. Phosphorus releases were stimulated in the test system on a daily basis, and as the secondary effluent phosphorus concentration approached that of the primary effluent, high-level aeration was resumed in the aeration tank to facilitate a rapid recovery of phosphorus removal. The response in Figure 10 indicates that, reproducibly, a significant phosphorus release can be stimulated within six hours of lowering the level of aeration and that complete recovery can be attained within approximately 10 hours of restoring high-level aeration to the system. It should be emphasized that the final effluent samples represent an approximate eight-hour lag compared to the primary effluent and the secondary effluent observations represent about a two-hour lag compared to those taken at the end of the aeration tank. During the study, the monitoring system was operated in the three-point mode, so



D O VARIATION TEST NO.3 - GRADUAL CHANGE ON TEST SYSTEM
FIGURE 9



D O VAR ATION TEST NO.4 - RAPID CHANGE ON TEST SYSTEM

FIGURE 10

that visual interpretation of the instrument analog chart output permitted immediate assessment of the final effluent phosphorus concentration and precise adjustment of aeration when the desired conditions were reached in the activated sludge system.

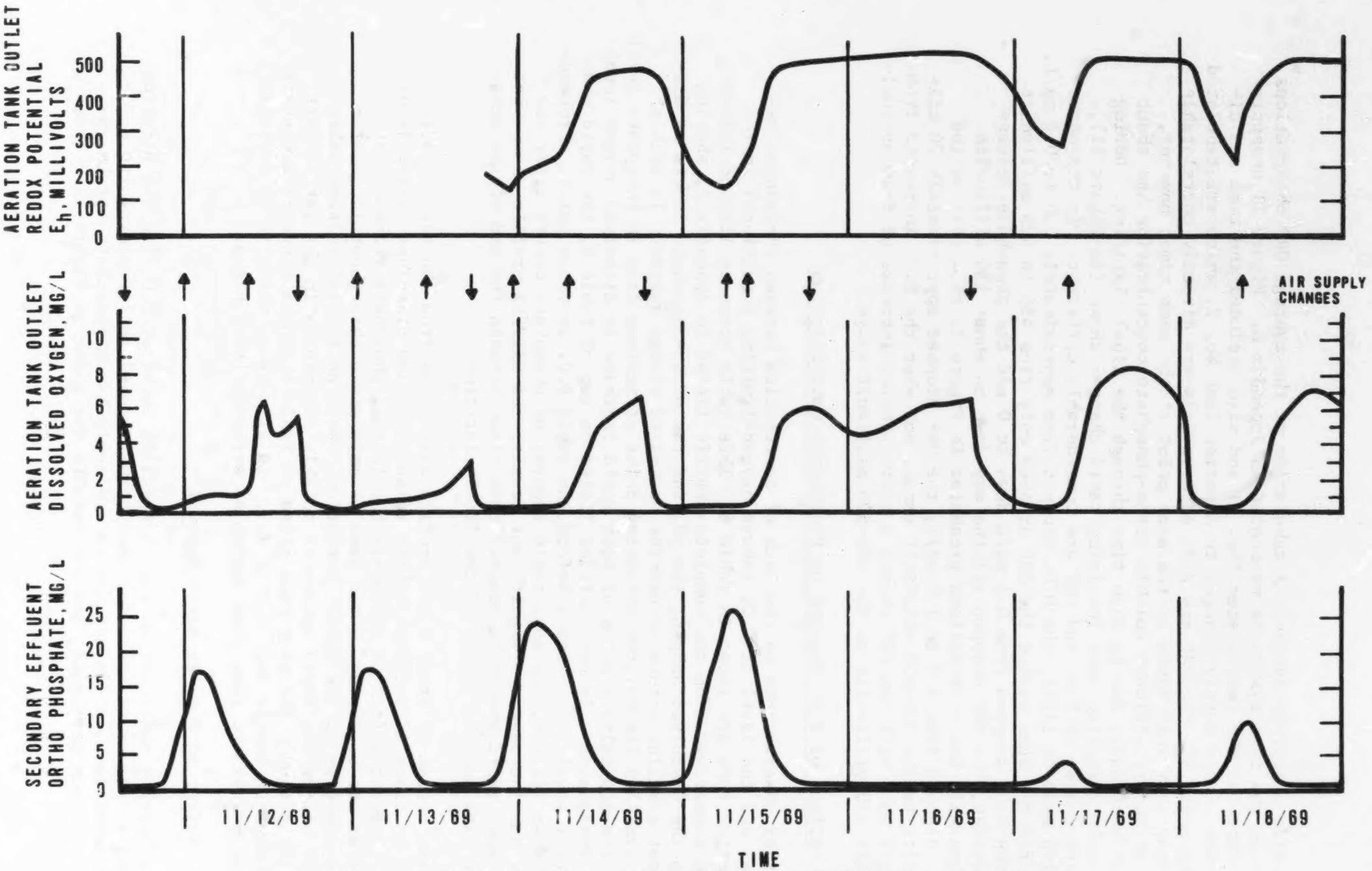
The performance of the control system during the study presented in Figure 10 was similar to that shown in Figure 9 for the first six days, with the effluent concentration of ortho-phosphate being equal or less than 0.3 mg P/L. This performance was not impaired by the fact that, when changing the aeration rate from approximately 8,500 scfm (in each aeration tank) to a phosphorus release test condition of 13,000 scfm in Aeration Tank No. 1 and 4,500 scfm in Aeration Tank No. 2, the flow through Aeration Tank No. 1 was increased by 10 percent and the flow to Aeration Tank No. 2 was decreased by approximately 10 percent.

Some impairment in phosphorus removal in the control system was observed on 11/17 and 11/18 (Figure 10). The only abnormal operating condition during that time was an unusually high sludge wasting rate early in the morning on 11/17 and again early in the afternoon on 11/17. The high wasting rate (approximately 10 to 15 times normal) caused aeration tank mixed liquor suspended solids concentration to drop from approximately 2,100 to 1,600 mg/L. During this same period, there was some excessive wasting on System 2; however, the aeration tank suspended solids showed only a 200 mg/L decrease. An expanded chronological plot of the phosphorus data presented in Figure 10 showing the actual data points can be seen in Appendix B.

The association of impairment of carbon removal with low D.O. phosphorus release is not extremely obvious or conclusive. The soluble carbon content is constantly varying both in primary and secondary effluent, and since there are always significant carbon levels in the final effluent, effects caused by process changes are frequently overshadowed by wastewater variations. At normal operating conditions, both test and control systems produced essentially identical carbon removal performance. Therefore, based on the assumption that the control system effluent concentrations are valid comparison bases for the test system potential removal at any specific time, Table 5 presents one approach of associating carbon performance impairment with phosphorus releases caused by a low D.O. condition. The carbon and phosphorus final effluent differences between the two systems are shown for three cases, all of which closely associate carbon effects with phosphorus releases at these apparently oxygen limiting conditions. In all three cases, as soon as the secondary effluent phosphate concentration increased in the test system, the total carbon concentration increased too, with respect to the test system. Although impairment in carbon removal was not as significant as that for phosphorus removal, it still was observable.

D.O. - ORP Relationships

Figure 11 presents the limited Oxidation-Reduction Potentional (ORP) observations that took place during test period 13. The ORP is reported in terms of E_h, millivolts referenced to hydrogen electrode. The instrument system used to measure the data in Figure 11 was a silver-silver



TEST ACTIVATED SLUDGE SYSTEM OUTLET
ORP, DO, AND ORTHO PHOSPHATE
FIGURE 11

chloride electrode system. A tabulation of the average ORP observations made on the test system is presented in Appendix A. Figure 11 presents the data for the test system (No. 2) and also includes the time and direction of air supply changes to Aeration Tank No. 2, which are tabulated in Appendix A. The ORP and D.O. observations are directly correlatable because they were taken at the same point at the same time; however, the secondary effluent soluble ortho-phosphate concentration has about a two-hour delay due to flow time through the final clarifier. During the D.O. variation test involving rapid changes shown (in Figure 11), the responses of D.O. and ORP are considerably different. In the observation made on 11/14, the D.O. dropped from approximately 6.0 to 0.4 mg/L, and for the same period the ORP dropped only from 485 to 425 millivolts. As the D.O. dropped from 0.4 mg/L down to 0 and the phosphate release proceeded, the ORP dropped all the way down to about 150 millivolts. In general, the observations presented in Figure 11 show that as the D.O. dropped from 4.0 to 1.0 mg/L, the ORP dropped approximately 70 millivolts to the 350-450 millivolt range, but when the D.O. increased from 1 mg/L to 4 mg/L the ORP showed a corresponding increase of from approximately 110 millivolts to the 450-500 millivolt range.

Effect of D.O. Changes on Phosphorus Concentration

Further observations on the lack of correlation between phosphorus removal and the level of D.O. (above oxygen-limiting conditions) in the aeration tank are shown in Table 6. This table presents limited information summarized from the complete profile listed in Appendix A, showing only the dissolved oxygen, the pH, and the ortho-phosphate levels at different sampling points across the activated sludge system. In each of the profiles listed, the estimated point of maximum drop in phosphate level and the approximate point of most rapid increase in dissolved oxygen level are designated. In the profiles listed on top of Table 6, the rapid phosphate removal point occurs before the rapid D.O. increase point. Proceeding down Table 6, the most rapid removal of phosphate occurs after the D.O. has increased to significant levels; the 8/27/69 profile shows that the most rapid phosphate removal took place between the end of the aeration tank and the outlet of the final clarifier.

At the bottom of Table 6 are profile data taken from the test aeration tank at times of ortho-phosphate release and low dissolved oxygen level. The apparent effect is one where the initial phosphate release that occurs at the beginning of the tank is maintained throughout the system. This compares to the normal condition, where an initial release takes place before the rapid uptake of soluble phosphorus in the latter part of the system. The pH values given on Table 6 show a range of secondary effluent pH levels from 6.8 to 7.3. In all cases, there is an increase of pH across the plug flow system as aeration takes place.

Effect of D.O. on Batch Removal

As a further confirmation that a specific level of D.O. (in the aeration tank) is not as critical for phosphorus removal as is maintaining aerobic conditions, a limited laboratory-scale batch phosphate uptake experiment was performed, and the results are shown in Figure 12. These

Table 5

Association of Low Dissolved Oxygen Phosphate Release with Reduced Carbon Removal

Difference between Test and Control Secondary Effluent Orthophosphate and Total Carbon Observations (Monitoring Results Concentration Difference, mgP/L and mgC/L)

Case 1			Case 2			Case 3		
Time	P_2-P_1	C_2-C_1	Time	P_2-P_1	C_2-C_1	Time	P_2-P_1	C_2-C_1
10/27/69			11/11/69			11/14/69		
1700	No. 2 Air Reduced		1600	No. 2 Air Reduced		2000	No. 2 Air Reduced	
1900	0.2	0	1900	0	0	2200	0	0
2000	0.1	0	2100	0.1	5			
2200	0.8	3	2200	4.6	3	11/15/69		
2300	1.3	5	2300	9.0	5			
						0000	0	0
10/27/69			11/12/69			0100	1.9	15
						0200	5.7	15
0000	3.3	5	0000	10.1	0	0300	10.9	15
0100	4.9	10	0100	No. 2 Air Restored		0400	15.3	25
0200	7.4	--	0200	16.9	10	0500	20.3	20
0300	9.7	5	0400	13.7	5	0600	23.8	35
0400	12.7	0	0600	9.1	10	0700	No. 2 Air Restored	
0500	14.9	5	0800	4.8	5	0800	25.8	25
0700	18.9	10	1000	2.0	5	0900	23.5	40
0800	No. 2 Air Restored		1200	0.6	0	1000	21.5	30
0900	19.7	10	1400	0.1	0	1100	15.6	45
1100	15.8	10				1200	10.5	--
1200	11.5	10				1300	6.7	20
1300	8.1	5				1400	3.6	10
1400	5.2	5				1500	2.0	-5
1500	3.1	10				1600	0.8	5
1600	1.8	0				1700	0.2	0
1700	0.4	0				1900	0	0

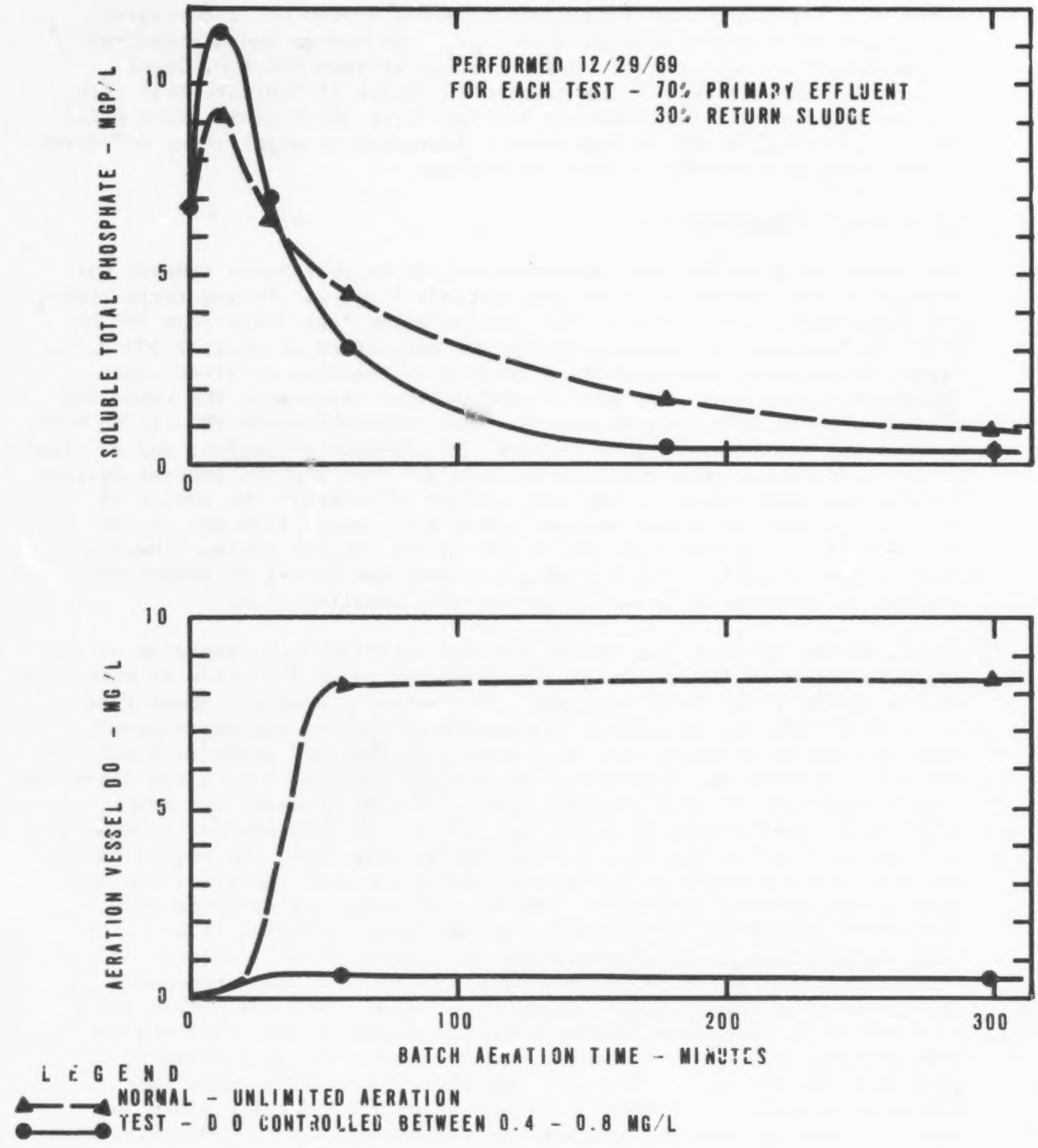
NOTE: At normal operating conditions on both systems, there is no significant difference in secondary effluent orthophosphate or total carbon between the two systems.

Table 6

Relationship Between Soluble Phosphorus and Dissolved Oxygen in the Activated Sludge System

	Sampling Position for Profile Study									
	PE	AT1	AT2	AT3	AT4	AT5	AT6	AT7	RS	SE
9/17/69-Test										
Ortho P, mgP/L	8.7	10.2 │	1.3	0.6 ¦	0.3	0.2	0.3	0.2	20.6	0.3
D.O., mg/L	-	0.0 │	0.1	1.2 ¦	3.6	5.4	5.6	6.6	-	1.6
pH	6.5	6.8 │	6.9	6.9 ¦	6.9	6.9	7.0	7.0	6.6	7.2
11/18/69-Control										
Sol.Tot.P mgP/L	8.0	27.5	17.7	6.8 │	2.0 ¦	1.1	0.5	0.3	15.4	0.6
D.O., mg/L	-	0.0	0.3	1.0 │	2.0 ¦	4.5	5.5	6.0	-	2.5
pH	6.3	-	-	- │	- ¦	-	-	-	-	7.0
12/3/69-Control										
Ortho P, mgP/L	8.7	30.2	24.4	16.3	5.5 │¦	1.0	0.5	0.3	46.4	0.3
D.O., mg/L	-	0.0	0.1	0.3	1.0 │¦	3.6	4.6	5.2	-	1.2
pH	6.6	6.6	6.7	6.8	6.8 │¦	6.8	6.8	6.8	6.5	6.8
12/10/69-Test										
Sol.Tot.P, mgP/L	10.8	30.0	29.4	18.0	8.4 │¦	4.2	3.6	-	50.0	1.4
D.O.,mg/L	-	0.0	0.1	0.3	1.4 │¦	4.7	5.7	6.4	-	0.5
pH	6.3	6.5	6.6	6.7	6.7 │¦	6.7	6.8	6.8	6.4	6.9
8/27/69-Control										
Ortho P, mgP/L	4.8	50.8	14.1 ¦	13.9	13.7	-	-	12.5 │	78.0	0.5
D.O., mg/L	-	0.0	- ¦	-	6.0	-	-	4.9 │	-	1.3
pH	6.4	6.6	- ¦	-	6.8	-	-	6.9 │	6.8	7.1
9/3/69-Control (1:00 AM from Monitoring Data)										
Ortho P, mgP/L	6.5	30.4	-	-	26.7	- ¦	-	20.5 │	40.2	0.9
D.O. mg/L	-	0.0	-	-	0.5	- ¦	-	3.3 │	-	0.2
pH	6.4	6.8	-	-	6.7	- ¦	-	6.7 │	6.7	6.8
10/23/69-Test										
Ortho P, mg /L	8.5	8.9	12.7	11.0	10.0	9.3	10.8	11.8	25.5	10.8
D.O. mg/L	-	0.0	-	-	0.1	-	-	0.3	-	0.1
pH	6.6	6.1	-	-	6.9	-	-	6.9	6.7	6.9
10/21/69-Control (5:00 AM from Monitoring Data)										
Ortho P, mgP/L	10.8	38.0	-	-	61.0	-	-	40.0	62.5	21.7
D.O. mg/L	-	0.0	-	-	0.1	-	-	0.4	-	0.1
pH	6.4	6.7	-	-	6.7	-	-	6.9	6.6	7.2

Note: "│" designates maximum P removal and "¦" designates maximum D.O. increase



EFFECT OF DISSOLVED OXYGEN ON LABORATORY – SCALE BATCH AERATION

FIGURE 12

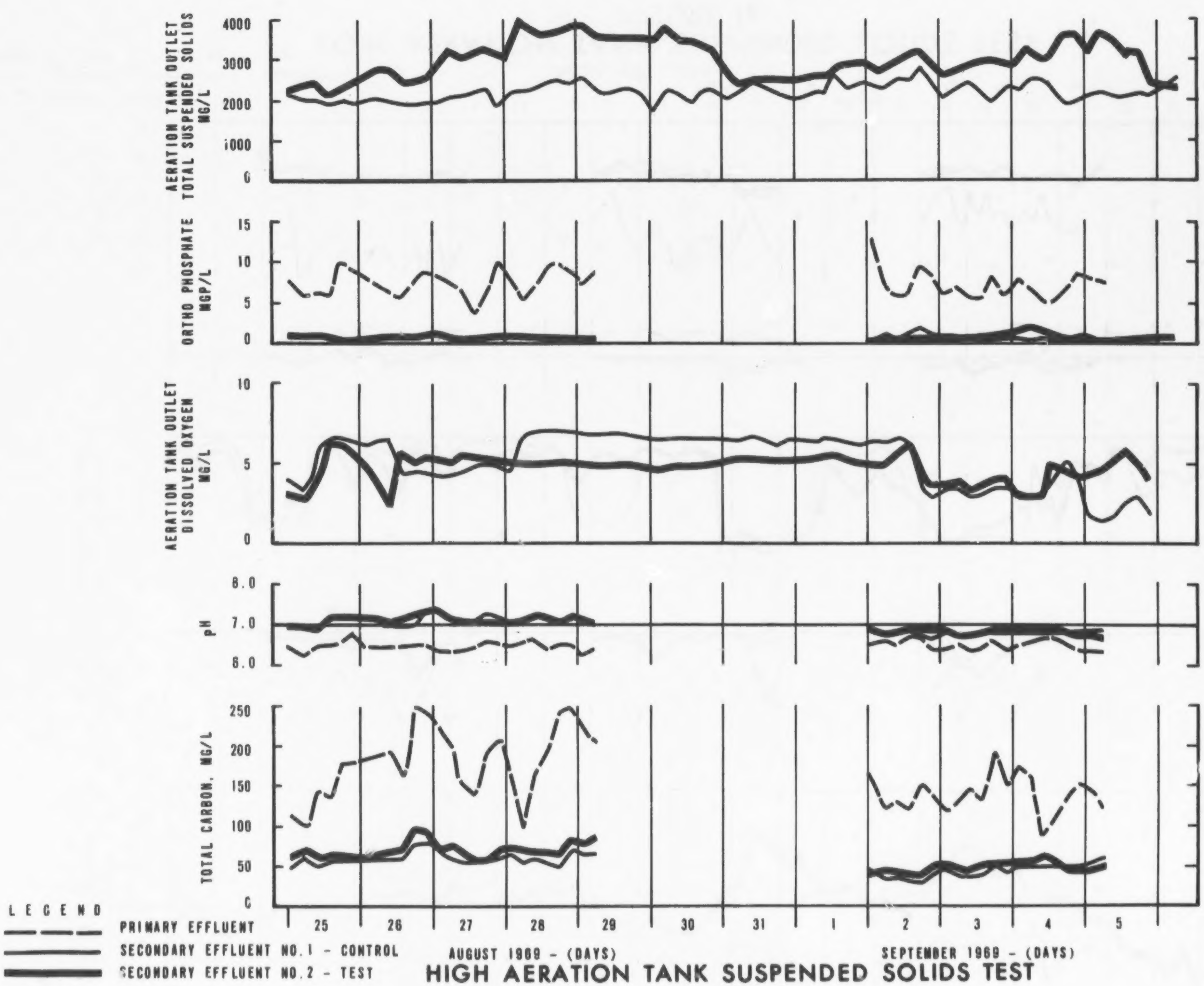
tests were performed with full-scale constrol System No. 1 activated sludge and primary effluent at Baltimore. One system had a dissolved oxygen detection and control system that maintained the D.O. level between 0.4 and 0.8 mg/L. The results in Figure 12 indicate that both systems were aerated continuously for the first 20 minutes, after which the D.O. controller was in operation. There was no significant difference in the phosphate removal of the two systems.

Variation in Suspended Solids

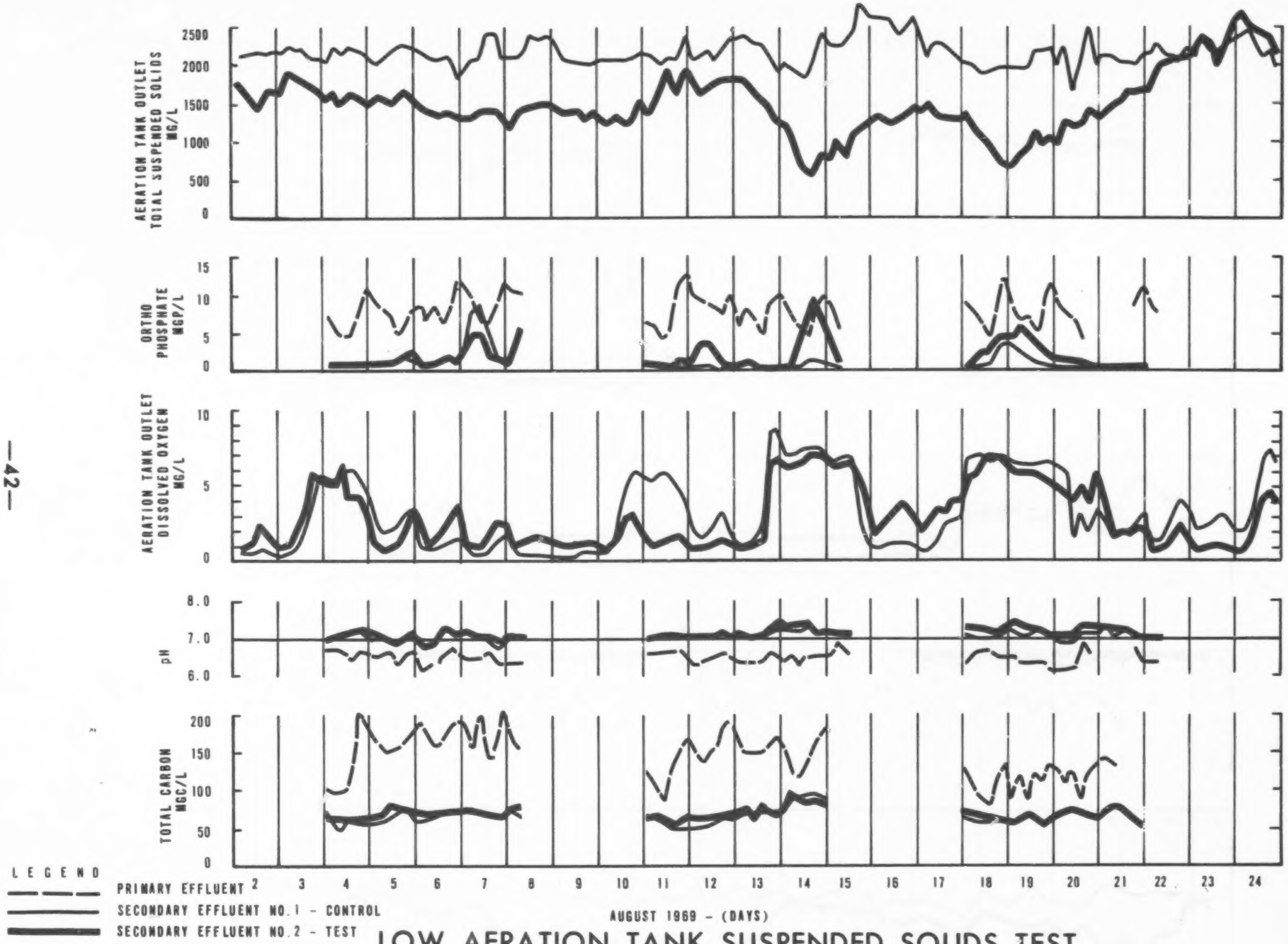
The effect of aeration tank suspended solids on phosphorus removal was studied on the System No. 2 in test periods 4 and 5. During these tests, the suspended solids level in the test aeration tank range from 590 to 3,990 mg/L, while the control system was maintained at about 2,000 mg/L. Figure 13 presents the monitoring results of the high aeration tanks suspended solids test. The gap in the analyses represents the Labor Day weekend when no data were collected. The ortho-phosphate removal in both systems was consistently good through the observation period, and no significant differences were observed between the test and the control systems. Bulking was experienced in the test system only during the period of 8/29 to 9/4 and the sludge volume index (SVI) ranged from 200 to 300 in the test system and from 100 to 150 in the control system. During much of test period 4, the second air blower was in use to assure maintenance of adequate D.O. levels in the test aeration tank.

A plot of the observations during the low aeration tank suspended solids study is shown in Figure 14. A sustained period of operation at suspended solids levels below 1,000 mg/L was not acheived. However, above this level of solids, no impairment of phosphorus removal was experienced. Some phosphorus releases were experienced in the test shown in Figure 14. The first release was experienced on 8/7 and was caused by a low dissolved oxygen condition in both aeration tanks. Another release was caused on 8/12 in the test system by a low D.O. level. On 8/14 another phosphorus release occurred in the test system, but at this time, the second blower was put into operation to be certain that a low D.O. condition was not causing the release condition. During this time, the aeration tank suspended solids reached a minimum of 588 mg/L. However, it is uncertain whether this phosphorus release was caused by the low level of suspended solids or by rapid wasting of the mixed liquor suspended solids which had taken place during the previous 24 hours. Then on 8/18 and 8/19, phosphorus releases were observed on both test and control systems. The test system minimum suspended solids reached at this time was 692 mg/L. However, immediately preceding these last releases, significant levels of solids reduction had taken place in both the test and control systems, to 500-700 mg/L over a 20-hour period. In these cases, when the abnormally high wasting rate was returned to normal, gradual recovery of phosphate removal was achieved.

During the overall project study period, other observations were made on the circumstantial connection between abnormally high levels of sludge wasting and a subsequent phosphorus release in the activated sludge system. One case described earlier was that depicted on Figure 10



HIGH AERATION TANK SUSPENDED SOLIDS TEST
FIGURE 13



LOW AERATION TANK SUSPENDED SOLIDS TEST
FIGURE 14

concerning D.O. studies, where an unexpected phosphorus release occurred in the control system, and previous excessive sludge wasting was the only condition that could be associated with the phosphorus release. On December 1, 1969, another phosphorus release occurred in the control system at a time of high D.O. in the aeration tank; the suspended solids level had been reduced from 2,050 to 1,750 mg/L because of the higher sludge wasting rate over the preceding 8-hour period. A final observation on the association of diminished phosphate removal associated with a high wasting was made in February 1970. Severe bulking had taken over the activated sludge system, and the operators wasted excess sludge over a short period of time, thus reducing the aeration tank suspended solids from above 2,000 down to about 1,000 mg/L. Although only limited phosphorus monitoring data were available in February 1970, results indicated that it took approximately one week for the system to recover to a high level of phosphate removal.

Profile observation on samples taken at different points in the activated sludge system while operating at different aeration tank suspended solid levels are listed in Table 7. While the activated sludge system was removing a high degree of phosphorus, the initial release of phosphorus at the beginning of the aeration tank increased with suspended solids, and the rate of phosphorus removal likewise increased. Additional observations showing this same effect in batch tests are presented in Figure 15. The batch tests were performed simultaneously. The time required to reduce the inlet concentration to a soluble ortho-phosphate level equal to or less than 0.4 mg P/L is related to the suspended solids, and is not necessarily a function of the inlet wastewater characteristics. Complete observations associated with Figure 15 are presented in Appendix A and include a thorough characterization as to the phosphorus, nitrogen, and carbon changes during these batch uptake tests.

The last factor related to suspended solids concentration was the inventory of solids in the final clarifier. The Baltimore activated sludge secondary clarifiers normally operate with a sludge depth of less than 1 foot in the bottom of the 13-foot side water depth. In one experiment, the return sludge recycle was dropped from the normal 25 percent to 10 percent. This action was unsuccessful in raising the final clarifier sludge depth above 2 feet, because the sludge condition was such that an increased underflow suspended solids concentration permitted the return of almost the same amount of suspended solids per unit time. However, at the two times when bulking was experienced in the test system and the secondary clarifier sludge blanket was within 2 feet of the overflow level (on 8/27 and 9/19), no reduction in phosphorus removal was experienced.

The only occasion where a significant phosphate release was observed to have taken place in the final clarifier was during a condition where the sludge collection mechanism was accidentally shut off for a period of two days (9/18 - 9/20). The resulting reduction in aeration tank suspended solids stimulated the operators to investigate and restore the clarifier to normal operation. Since this occurred on a weekend, continuous monitoring data for phosphorus release was not available, although limited grab samples indicated that a significant release did take place.

Table 7

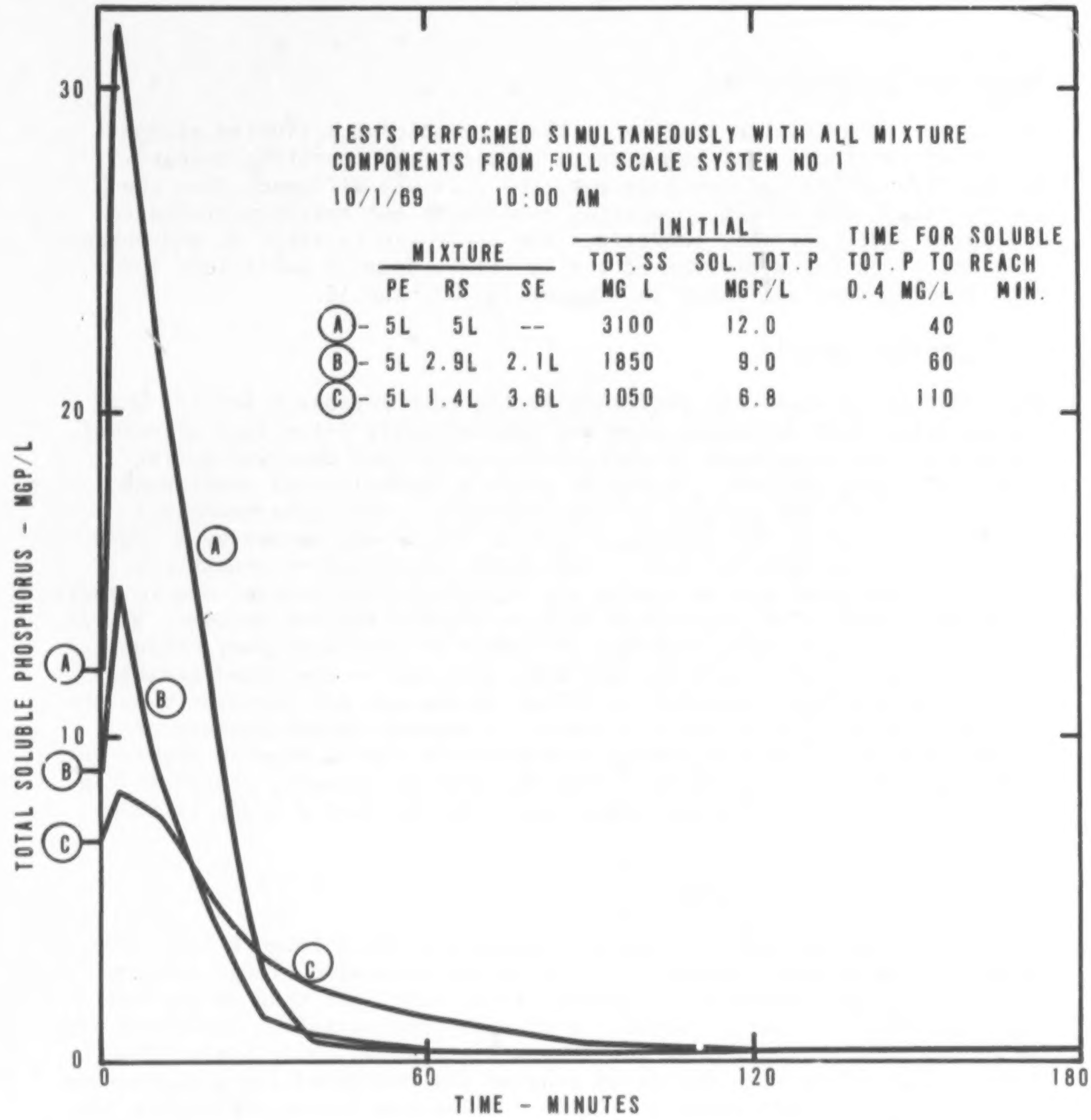
Summary of Profile Results at Various Suspended Solids Levels

Low Solids - 8/13/69 Daily Averages

	PE	AT1	AT2	AT3	RS	SE
SS, mg/L	112	1,400	1,360	1,540	6,540	12
Ortho PO_4, mgP/L	7.7	22.0	12.9	1.9	24.1	0.3
Total P, mgP/L	11.0	7.0	70	74	200	1.0
Sol. Total C, mg/L	115	720	85	80	105	70
Ammonia N, mg/L	24.4	21.8	18.0	16.5	22.5	16.3
Kjeldahl N, mg/L	-----	108	102	110	-------	----
Nitrate + Nitrite, mgN/L	0.07	0.3	0.1	0.2	-------	0.3
D.O., mg/L	-----	0.1	2.8	3.3	-------	2.3
pH	6.4	6.7	6.9	7.0	6.8	7.1
Flow, mgd	6.7	8.6	8.6	8.6	1.9	6.5

High Solids - 8/29/69 Daily Averages

	PE	AT1	AT2	AT3	RS	SE
SS, mg/L	144	3,730	3,840	3,760	8,860	5
Ortho PO_4, mP/L	8.1	45.8	13.7	2.2	47	0.2
Total P, mgP/L	-----	170	162	152	-------	1.5
Sol. Total C, mg/L	190	100	95	80	100	65
Ammonia N, mg/L	22.4	17.2	15.2	12.6	16.9	10.1
Nitrate + Nitrite, mgN/L	0.6	1.0	1.1	2.3	1.4	2.3
D.O., mg/L	-----	0.0	3.1	5.0	-------	0.6
pH	6.5	6.7	6.8	6.8	6.6	7.1
Flow, mgd	5.5	9.1	9.1	9.1	3.6	5.4



TESTS PERFORMED SIMULTANEOUSLY WITH ALL MIXTURE COMPONENTS FROM FULL SCALE SYSTEM NO 1

10/1/69 10:00 AM

MIXTURE				INITIAL		TIME FOR SOLUBLE TOT.P TO REACH 0.4 MG/L MIN.
	PE	RS	SE	TOT.SS MG L	SOL. TOT.P MGP/L	
Ⓐ-	5L	5L	--	3100	12.0	40
Ⓑ-	5L	2.9L	2.1L	1850	9.0	60
Ⓒ-	5L	1.4L	3.6L	1050	6.8	110

LABORATORY BATCH TESTS AT VARYING SOLIDS LEVELS
FIGURE 15

Variations In System Flow

The effect of hydraulic loading on the conventional activated sludge system at Baltimore was evaluated by studying the operating results during five of the test periods when the flow was different than the design flow. The average operating conditions and system performance for three different flow conditions are presented in Table 8, and chronological plots for a portion of the low-flow, diurnal variation, and high-flow studies are shown in Figures 16, 17, and 18.

Low-Flow Studies

The low-flow studies were performed during test periods 6 and 12, when the aeration tank detention time was approximately twice that of normal operation. No impairment in phosphorus removal was observed during either of these studies. Figure 16 shows a chronological monitoring data plot of a 4-day portion of test period 6. The ortho-phosphate release observed in the control system on 9/9/69 was caused by a low D.O. condition in the aeration tank. The slight reduction of phosphorus removal in the test system during the release in the control system indicated the possibility of limited leakage between the two systems. It is also interesting to note that the pH levels of both secondary effluents were quite similar and not specifically affected by the added aeration time. The phosphorus removal in either system was not impaired when the secondary pH dropped to the 6.6 level. A typical diurnal change of primary effluent ortho-phosphate concentration can be seen in Figure 16. From this table, it can be seen that the highest incoming phosphate concentrations were experienced consistently in the last 8 hours of each day.

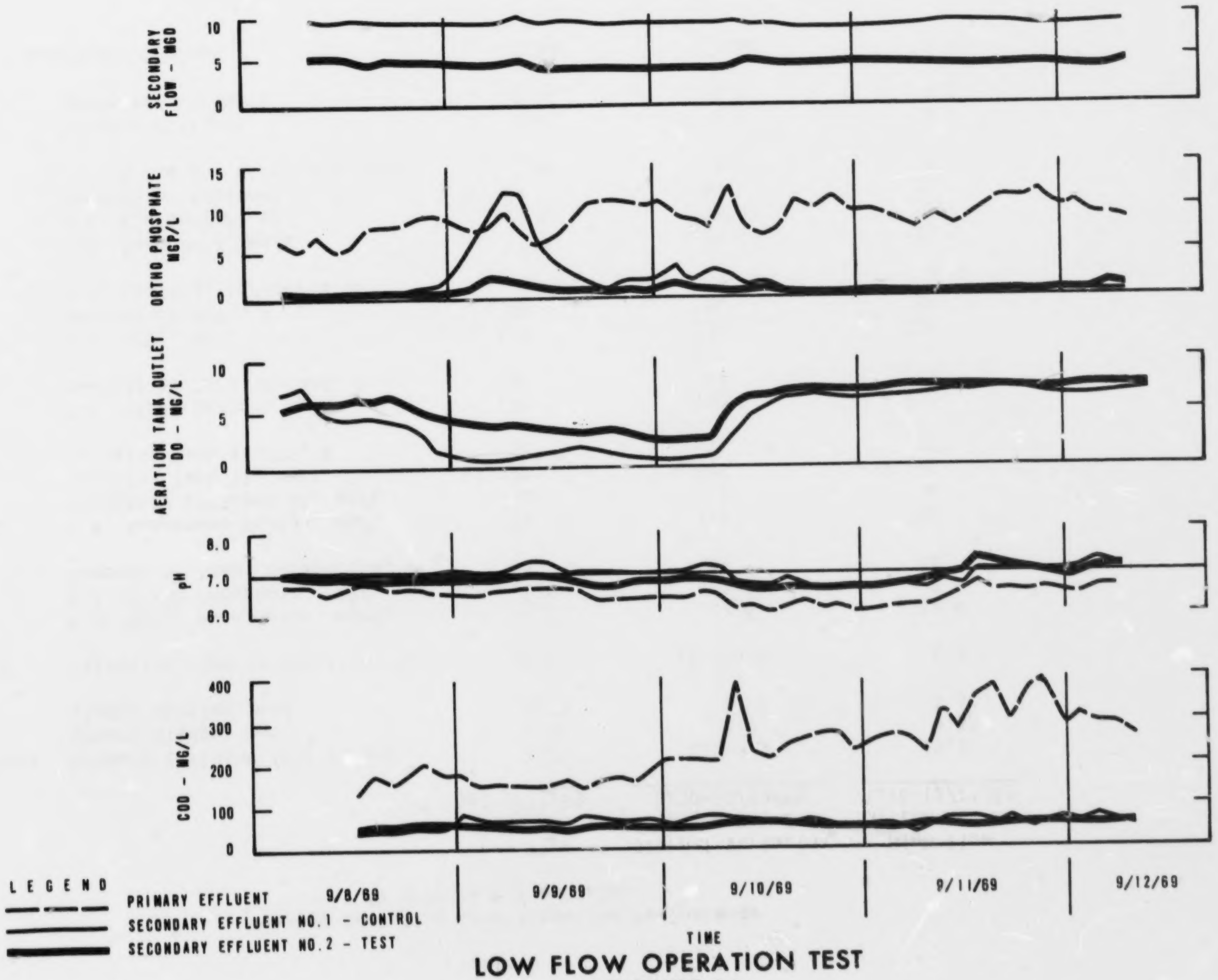
Diurnal Flow Variation

Due to the current unit process arrangement at the Baltimore Back River Wastewater Treatment, wastewater flow to the activated sludge portion is generally maintained at a constant rate, with less than 10 percent variation over any daily period. A diurnal flow variation study was set up during test period 8 when the flow was varied on daily basis from 3 to 10 mgd. This flow variation program was continued for a eleven-day period, as previously shown in Figure 4. The continuous monitoring results for a 3-day portion of test period 8 are shown in Figure 17. During this particular study, the monitoring system was operated on a 40-minute sampling cycle so that a reasonably continuous record of performance was achieved with 36 observations per day at each sampling point. When the dissolved oxygen level in the aeration tank was not limiting, a high degree of phosphorus removal was obtained on both the control and test systems. Some difficulties were experienced in maintaining a constant flow on the control system, while accomplishing the desired flow variation on the test system. These difficulties were due to the requirement for cumbersome manual adjustments and correction for each flow change.

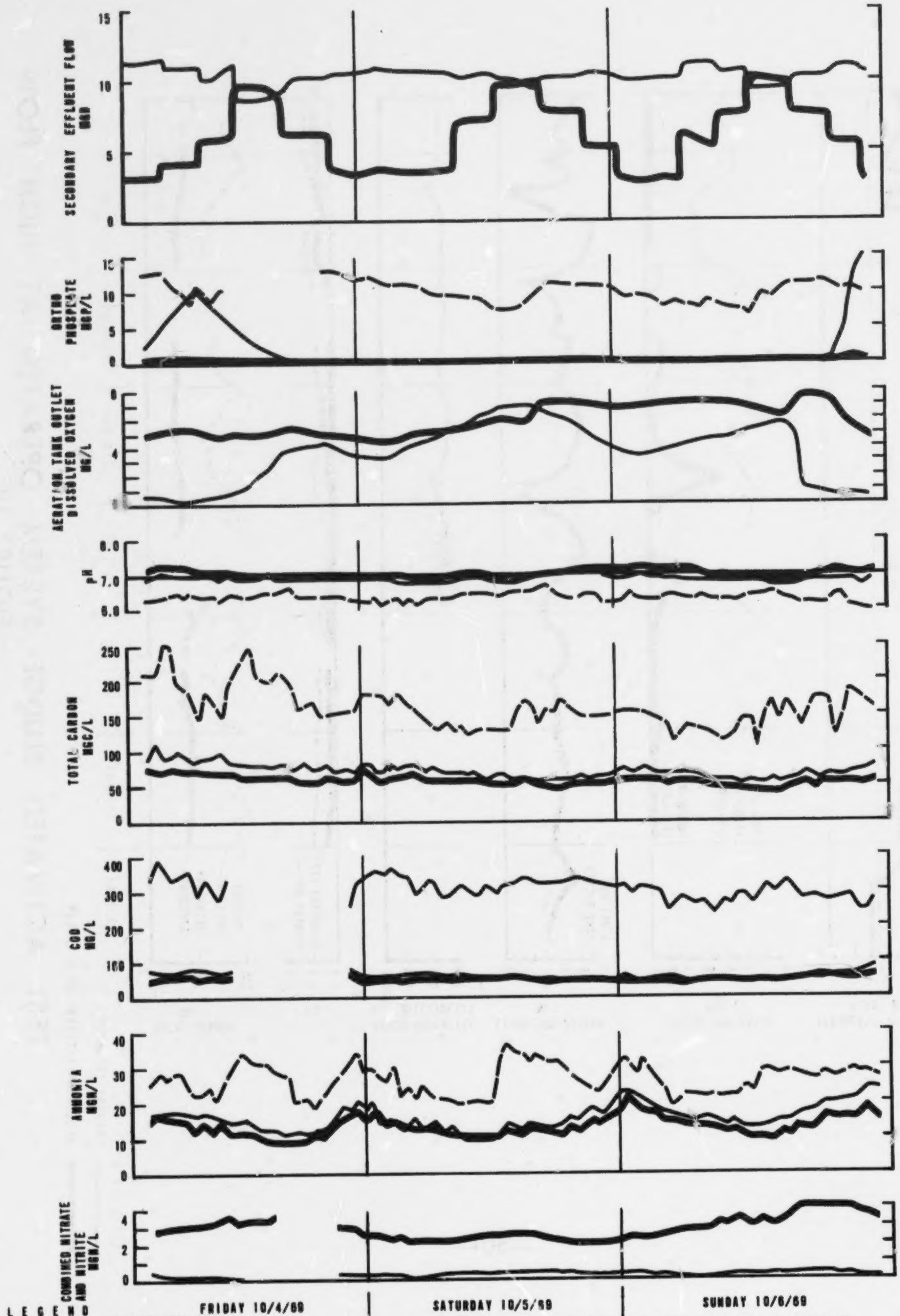
Table 8

Average Operating Conditions and Performance At Different Flow Rates

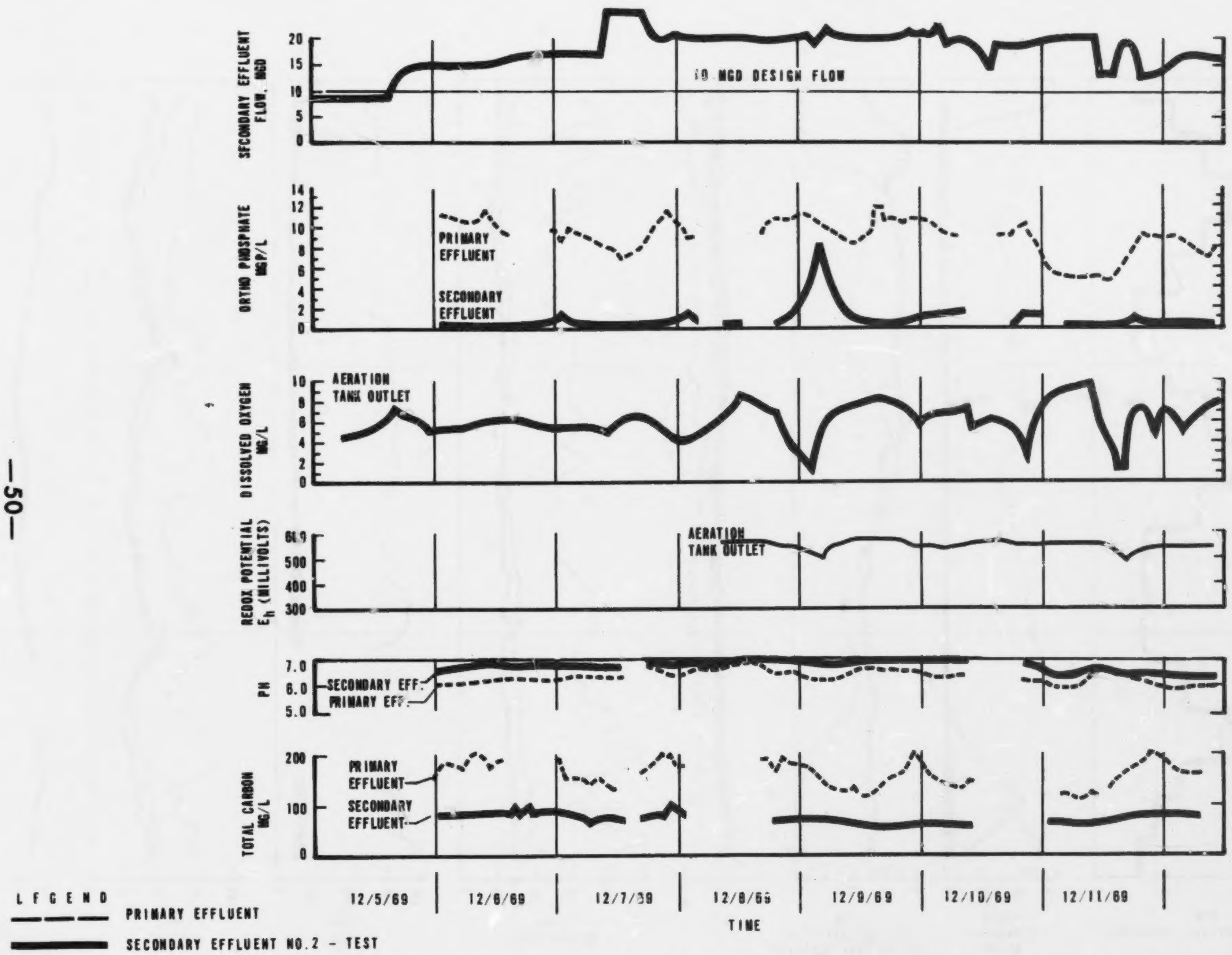
		Low Flow System No. 2 9/6-9/13/69	Diurnal Variation System No. 2 9/30-10/12/69	High Flow System No. 2 12/6-12/11/69
Flow	Primary Effluent (P.E.), mgd	4.7	2.8-9.5	19.3
	Return Sludge, mgd	1.5	2.0	4.35
	Sludge Wasting, mgd	0.18	0.16	0.30
DT	Detention Time in Aeration, hr.	10.0	13.0-5.4	2.3
P	P.E. Total Phosphorus, mgP/L	13.2	11.8	10.6
	P.E. Ortho Phosphate, mgP/L	8.0	9.5	9.0
	Removal of Total Phosphorus, %	86	89	88
SS	P.E. Suspended Solids, mg/L	173	171	102
	Secondary Effluent SS, mg/L	5	7	10
	Aeration Tank SS, mg/L	2,230	1,880	2,160
	Aeration Tank VSS/SS, %	68	71	77
C	P.E. Total Carbon, mg/L	113	139	156
	Removal of Total Carbon, %	62	71	77
BOD_5	P.E. BOD_5, mg/L	179	132	178
	Removal of BOD_5, %	85	90	90
	BOD_5 Loading, lb/day/lb SS	0.14	0.14	0.61
N	P.E. Ammonia N, mg/L	17.7	23.9	29.5
	P.E. Kjeldahl N, mg/L	23.9	28.4	31.9
	Removal of Kjeldahl N, %	67	40	37
	S.E. Nitrate + Nitrite N, mg/L	3.0	1.3	0.7
pH	Primary Effluent	6.5	6.4	6.4
	Secondary Effluent	6.8	7.0	6.9
Air Supplied SCFM/gal		3.42	2.68	1.15



LOW FLOW OPERATION TEST
FIGURE 16



DIURNAL FLOW VARIATION TEST
FIGURE 17



TEST ACTIVATED SLUDGE SYSTEM OPERATED AT HIGH FLOW
FIGURE 18

The ortho-phosphate monitoring data in Figure 17 indicated extremely good removal on both systems. On 10/5, the average secondary effluent ortho-phosphate concentration was 0.2 and 0.1 mg P/L for the control and test systems, respectively. With an average primary effluent feed concentration of 9.4 mg/L, these values represent ortho-phosphate removal of more than 97 percent.

Additional monitoring parameters are shown in Figure 17. Since the average loading and aeration time in the test system is considerably lower than those in the control system, the total carbon and COD removals are slightly higher. The primary effluent COD and total carbon removals show a similar variation with time. The inlet primary effluent data show considerable variation in ammonia concentrations with time. In particular, on 10/5 in a one-hour period, the ammonia level showed a rapid increase from approximately 20 mg N/L to 38 mg N/L, and the corresponding delayed effect on the ammonia level in the final effluent can be seen. During the period of observation, the test system had a considerably higher effluent combined nitrite-nitrate concentration and this difference corresponds to the lower secondary effluent ammonia levels observed in the test system. This visual comparison of actual monitoring data demonstrates the apparent independence between primary effluent phosphorus, nitrogen, and total carbon levels. The most significant nitrite-nitrate levels in the activated sludge secondary effluent were observed when low-flow experiments were being conducted; however, the effluent combined nitrate-nitrite concentration was never observed to be above 6.0 mg N/L.

High-Flow Studies

Two high-flow experiments were conducted during test periods 7 and 16. Test period 7 was unsuccessful because a bulking activated sludge condition took place requiring corrective measures. Also, during test period 7 only one clarifier was used with the Aeration Tank No. 2. The secondary clarifiers were designed for an overflow rate of 1,000 gpd/sq.ft. including return sludge. Operating experience demonstrated that at normal sludge conditions, rising secondary clarifier sludge blanket problems were experienced if the primary effluent flow to each system was raised above 12 mgd. Therefore, to assess the phosphorus removal at a high-flow condition during test period 16, the test Aeration Tank No. 2 was used in conjunction with both final clarifiers.

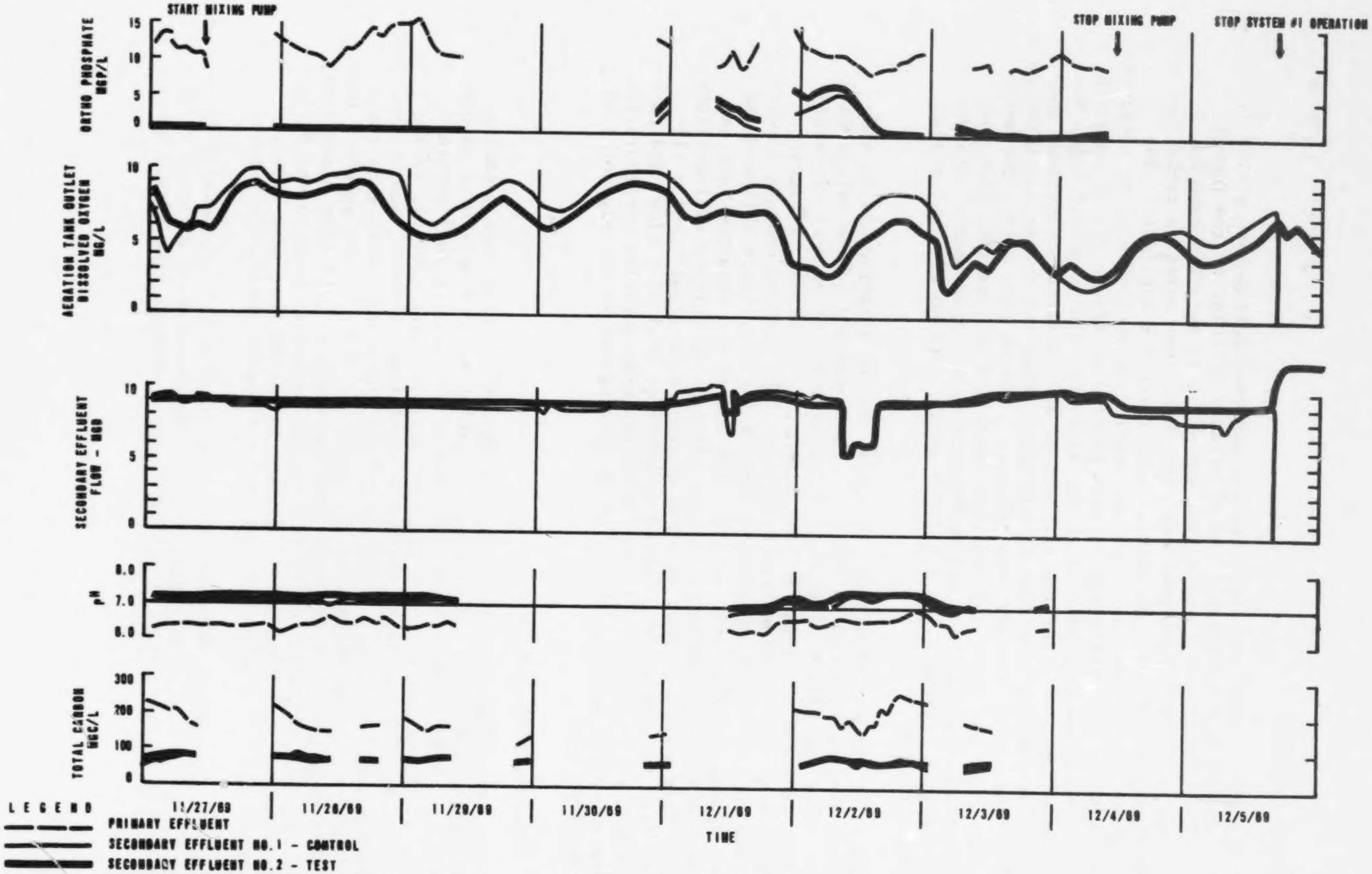
Figure 18 shows the results of the high-flow experimentation. With flow levels above the 10 mgd design value, phosphorus removal was good, provided that the aeration tank dissolved oxygen was maintained at an adequate level. For an eight-hour period on 12/7 the aeration tank detention time was 2.1 hours (while the primary effluent flow was up to 24.8 mgd for one-half of the system), and the activated sludge loading was approximately 0.67 lb BOD_5/lb SS/day. However, at this high flow rate, even through the sludge volume index was in the normal the 150-175 range, sludge blanket rising difficulties were experienced in the final clarifiers and the flow had to be reduced to 20 mgd (double the design of flow). Observation of the total carbon COD and BOD removals during test period 16 did not indicate serious degradation or downward trends in effluent quality. A profile study (Table 8) made 10 December 1969 during the high-flow study, indicated the capacity of the system for higher flows.

Variations in Mixing Configuration

The study of effects of variations in mixing configuration included such deviations from conventional activated sludge plug flow as modifications toward complete mixing, toward step aeration, and toward contact stabilization. The detention time response of the aeration tanks at these different mixing configurations to a slug introduction of tracer was previously presented in Figure 3. All tracer studies performed in this study and in previous work at the Baltimore activated sludge system showed that the aeration tank closely approached theoretical modal detention times. At normal design operation, the aeration tank tracer response approached that expected of plug flow, and was somewhat better than anticipated for six completely-mixed tanks in series. For this project, each deviation from normal plug-flow operating conditions was studied for approximately one week, and at the termination of each study, the system was returned to plug flow to assure prompt return to normal phosphorus removal operation.

Complete Mixing

A modification to simulate complete mixing was achieved by pumping 7 mgd of the mixed liquor from the end of the test aeration tank back to the beginning of the tank. This minor modification was unsatisfactory in achieving complete mixing, but did represent some deviation from normal plug flow operation. A plot of the monitoring data for this test is presented in Figure 19. The control system was operated at normal conditions, while the modification toward complete mixing was made on the test system. As can be seen on Figure 19, some automatic instrumentation problems were experienced, which limited the monitoring results. Some phosphorus release situations were experienced, but since they occurred on both the test and control systems, no conclusive statements could be made concerning the effect of this modification. These partial phosphorus releases occurred even though the D.O. was sufficiently high not to be a limiting factor for phosphorus removal. As stated previously, excess sludge wasting activity was high on November 30 and December 1 for both systems and appears to have stimulated this release. However, on December 2, a low-flow condition in both systems was caused by necessary treatment plant repairs upstream in the system. This low-flow apparently stimulated the recovery of a high level of phosphorus removal in both systems.



FLOW CONFIGURATION TEST NO.1 - MODIFICATION OF PLUG FLOW TOWARD COMPLETE MIXING
FIGURE 19

Step Aeration

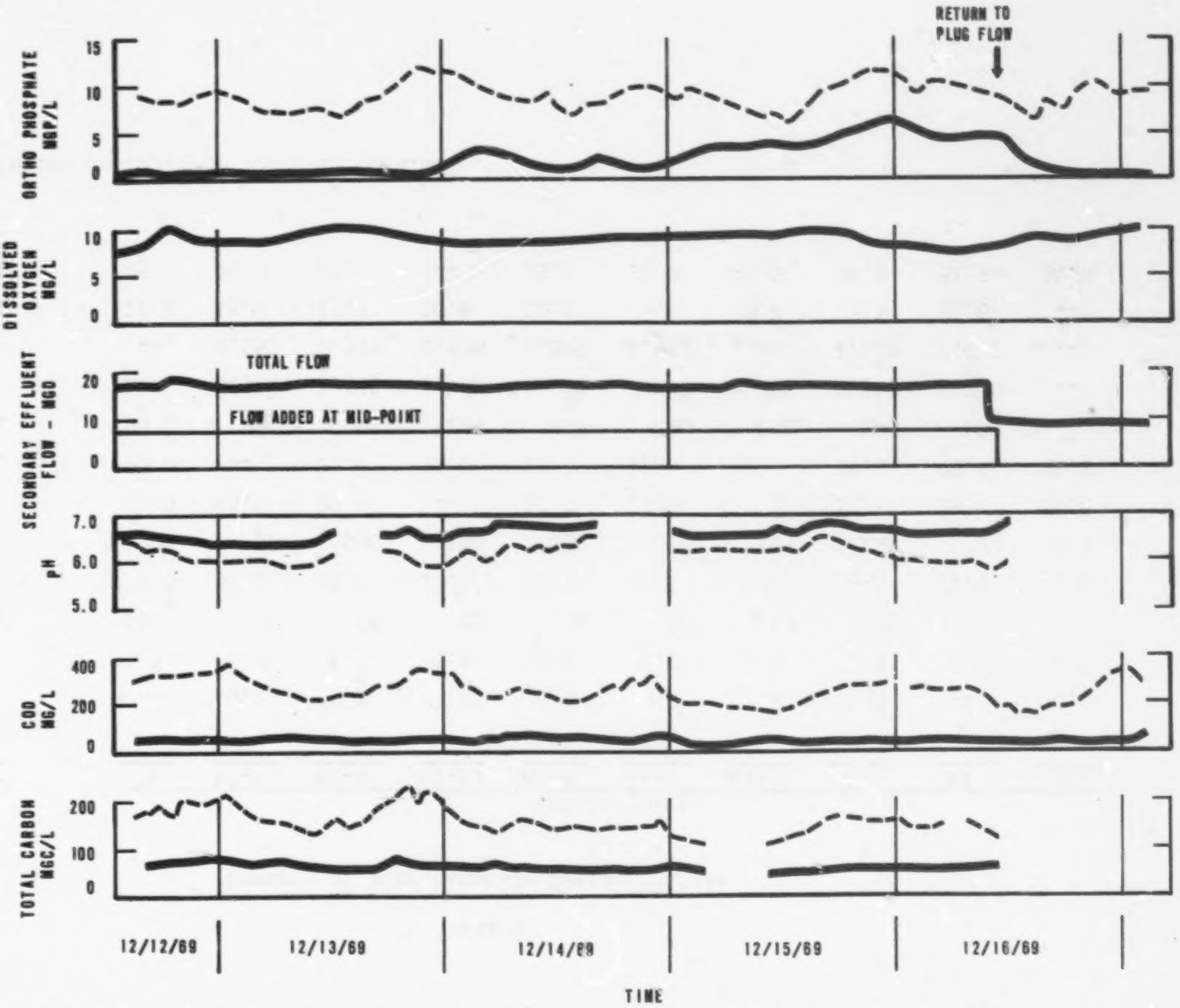
A modification toward step aeration was achieved during test period 17 by introducing approximately 7 mgd of primary effluent at the normal inlet and an additional 7 mgd at the mid-point in Aeration Tank No. 2. Both final clarifiers were operated with these test aeration tanks during test period 17; thus, no control comparison was available. The modification toward step aeration was started-up at 1:00 a.m. on 12-12-69. As indicated by the monitoring results plotted on Figure 20, an impaired condition of phosphorus removal in the activated sludge system began approximately two days after the start-up of step aeration operations and continued during the remainder of the test. When the system was returned to plug flow, total recovery was achieved. During this study, the aeration tank D.O. was above the limiting range and the aeration tank suspended solids concentration was maintained at a comparatively constant level (ranging between 2,000 and 2,300 mg/L), with no abnormal sludge wasting activity.

A summary of the aeration tank profile at the termination of the step aeration studies is shown in Table 9. The suspended solids values in Table 9 show the effect of the mid-point addition of primary effluent and also indicate a minimum of back mixing of the primary effluent introduced at the aeration tank mid-point. The ortho-phosphate results indicate that a release observed on the mixing of primary effluent and return sludge occurred only at the inlet end of the aeration tank and not at the mid-point where the second addition of primary effluent took place. This aspect of step aeration operation is significantly different from that normally observed in profiles from plug flow, and that the amount of phosphorus not removed by the step aeration configuration is approximately equal to that quantity introduced at the mid-point of the aeration tank.

Contact Stabilization

The final experiment in the mixing configuration series was a mixing modification toward the contact stabilization mode of activated sludge treatment. This condition was achieved by introducing only return sludge at the normal inlet of the test aeration tank (No. 2), making the first half of the aeration tank a stabilization basin, and by introducing 8 mgd of primary effluent at the mid-point, which made the final half of the aeration tank the contact portion of the system. During this study the test aeration tank was operated with both clarifiers, resulting in a slightly longer than normal detention time in the clarifiers; however, previous low-flow tests indicated that this longer secondary clarifier detention time did not impair phosphorus removal.

A plot of the monitoring results of this final study is presented in Figure 21. Contact stabilization operation was started early on 12/18 with a stabilization time of 9.2 hours and a contact time of 2.7 hours.



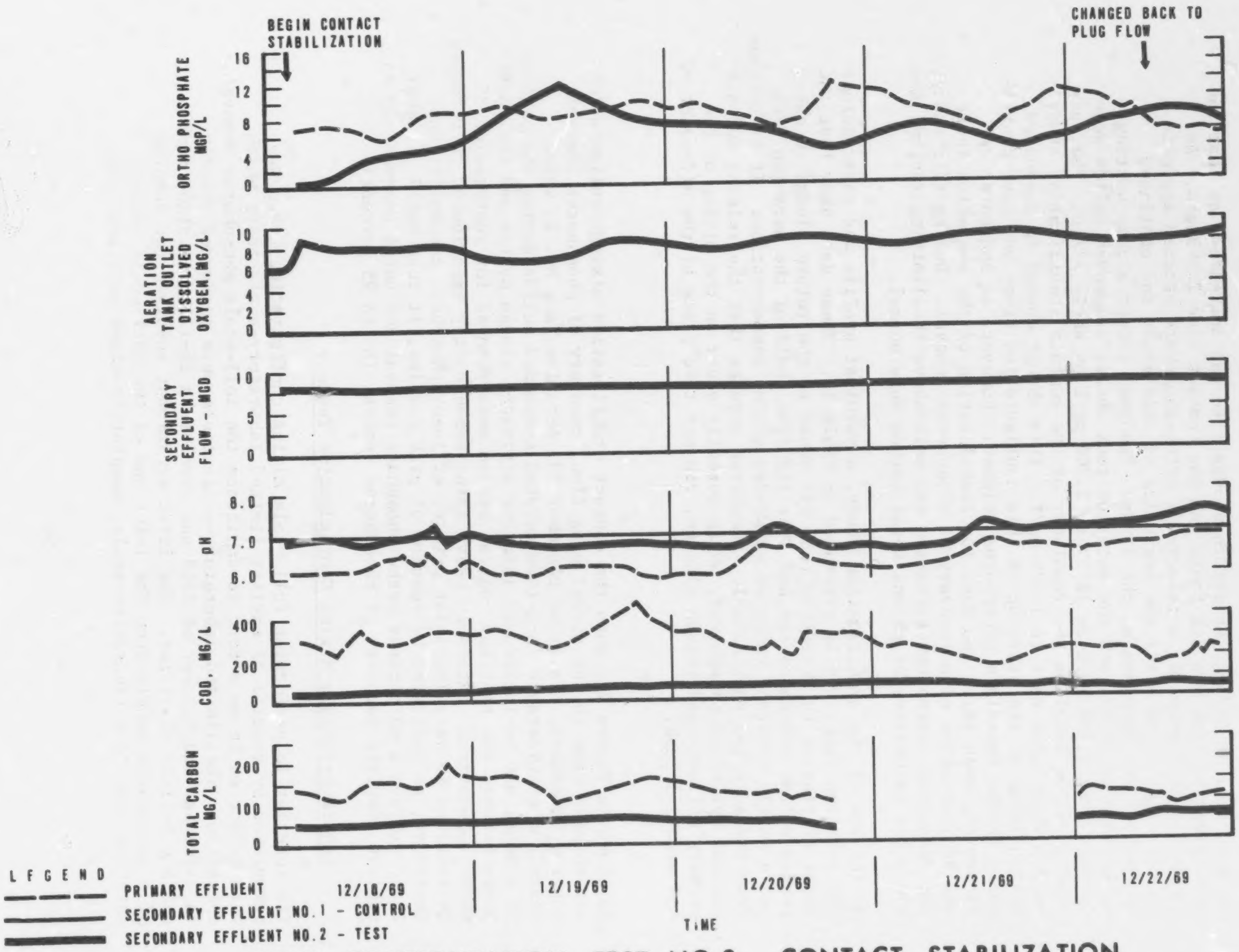
FLOW CONFIGURATION TEST NO.2 - STEP AERATION
FIGURE 20

Table 9

Summary of Step Aeration System Profile

Parameter	Sample Point PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
DO, mg/L	--	0.2	0.2	1.2	0.3	5.2	7.2	7.8	--	2.0
pH	6.3	6.5	6.5	6.5	6.7	6.7	6.8	6.8	6.4	6.8
Sol. COD, mg/L	180	75	65	70	60	60	60	60	100	55
Ortho PO_4, mg/L	9.8	30.7	21.4	12.1	11.5	5.1	3.6	--	41.5	4.4
Tot. P, mg/L	10.6	192	190	188	130	130	125	128	510	6.8
NH_3-N, mg/L	23.9	23.8	22.3	--	20.9	19.2	18.3	17.5	23.0	18.6
Sol. Tot. KN, mg/L	26.0	--	22.4	21.0	21.0	19.4	19.0	18.2	23.5	21.2
Tot. KN, mg/L	28.0	224	227	225	208	198	200	196	600	--
SS, mg/L	112	3,540	3,535	3,450	2,285	2,240	2,295	2,325	9,730	--
VSS, mg/L	--	2,550	2,575	2,500	1,640	1,650	1,640	1,685	7,085	--
Sol. Mg, mg/L	12.4	15.8	13.7	10.4	10.2	8.7	8.4	8.1	16.6	--
Sol. Ca, mg/L	25.0	26.0	25.5	--	25.3	24.2	25.0	24.2	31.5	24.0

(Samples collected on 12/16/69 10:00-12:00 a.m.)



FLOW CONFIGURATION TEST NO.3 - CONTACT STABILIZATION
FIGURE 21

At 8:00 a.m. on 12/19, the return sludge rate was increased, so that the stabilization time was 6.6 hours and the contact time 2.5 hours. As indicated in Figure 21, a release of ortho-phosphate started approximately eight hours after the beginning of this study and continued throughout the duration of the study. Abnormal excess sludge wasting took place on 12/17, and the aeration tank outlet suspended solids were reduced from 2,700 mg/L on 12/17 to 1,700 mg/L by early 12/18. The suspended solids level in the remainder of the contact stabilization study ranged from 1,500 mg/L to 1,800 mg/L. This abrupt change in suspended solids level at the start-up of this configuration study may have contributed to the immediate phosphorus release. However, as indicated on Figure 21, even after two days for stabilization of the operation there was no indication of a recovery of phosphorus removal. During this study, the dissolved oxygen concentration was well above the limiting ranges, and the other parameters of pH and total carbon were normal.

At the end of the stabilization study, a terminal profile was taken across the aeration tank, and is presented in Table 10. These data show that the first quarter of the aeration tank was equal to the return sludge in suspended solids concentration and that the final half of the aeration tank had a fairly constant range of suspended solids concentration. It is obvious from the aeration tank soluble phosphorus results that the release and subsequent uptake of phosphorus, which normally occur on the mixing of the primary effluent and return sludges, did not take place at the mid-point of the aeration tank.

As shown in Figure 21, when the contact stabilization mixing configuration was changed back to the normal plug flow, recovery of phosphorus removal was not immediate. Early on December 23, Aeration Tank No. 1, which contained considerable long-term aerated suspended solids during the period of outage, was re-introduced into the activated sludge system and the partitions between the test and control system were removed for restoration of normal operation. Extremely heavy rains subsequently experienced on December 24 resulted in very low inlet primary effluent phosphate concentrations. Therefore, as indicated by results of grab samples, it took until December 25 to achieve a 60 percent ortho-phosphate removal and until December 29 to achieve complete recovery of phosphorus removal (85 to 95 percent).

Laboratory-Scale Mixing Configuration Tests

The interest in performing full-scale mixing configuration tests was stimulated by results of earlier limited laboratory-scale tests which were conducted in an effort to duplicate the full-scale phosphorus removal operation. The limited laboratory-scale tests were performed chiefly in September and October of 1969 and involved a 15-liter aeration tank and a 4.5-liter clarifier. The first experiment involved the pumping of a continuous sample from the inlet end of the full-scale control aeration tank to a laboratory-scale, completely-mixed aeration tank.

Table 10

Summary of Contact Stabilization System Profile

Parameter	Sample Point									
	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
		Stabilization			Contact					
DO, mg/L	0.0	1.6	2.5	3.0	0.7	5.0	7.3	8.0	0.0	4.0
pH	6.7	6.9	6.8	6.9	6.9	6.9	7.0	7.0	6.8	7.1
Sol. Tot. P*, mg/L	9.6	10.2	9.6	9.2	9.8	9.0	9.6	8.8	24.0	8.8
Tot. P, mg/L	11.0	206	194	160	86	91	96	94	208	--
Sol. Tot. KN, mg/L	24.0	22.8	23.0	22.6	21.8	21.2	21.5	20.8	22.4	21.2
Tot. KN, mg/L	25.0	248	230	202	118	125	128	127	256	--
SS, mg/L	90	4,280	4,050	3,290	1,700	1,780	1,765	1,770	4,180	--
VSS, mg/L	70	3,095	2,925	2,460	1,335	1,430	1,325	1,330	3,270	--
Sol. Mg, mg/L	9.4	9.6	10.4	9.2	10.4	9.6	11.7	9.6	12.2	8.3
Sol. Ca, mg/L	22.0	22.5	22.5	22.5	21.5	21.5	22.5	22.5	25.5	22.0

* During this profile study ortho-phosphate values were not measured but soluble total phosphorus was performed instead.

(Samples collected on 12/22/69 10:00-12:00 a.m.)

Over a one-week period of continuous operation, the laboratory-scale aeration tank outlet soluble phosphate concentration showed good comparison to the full-scale system; phosphorus removal was good, with the soluble concentration in the effluent of less than 1.0 mg/L.

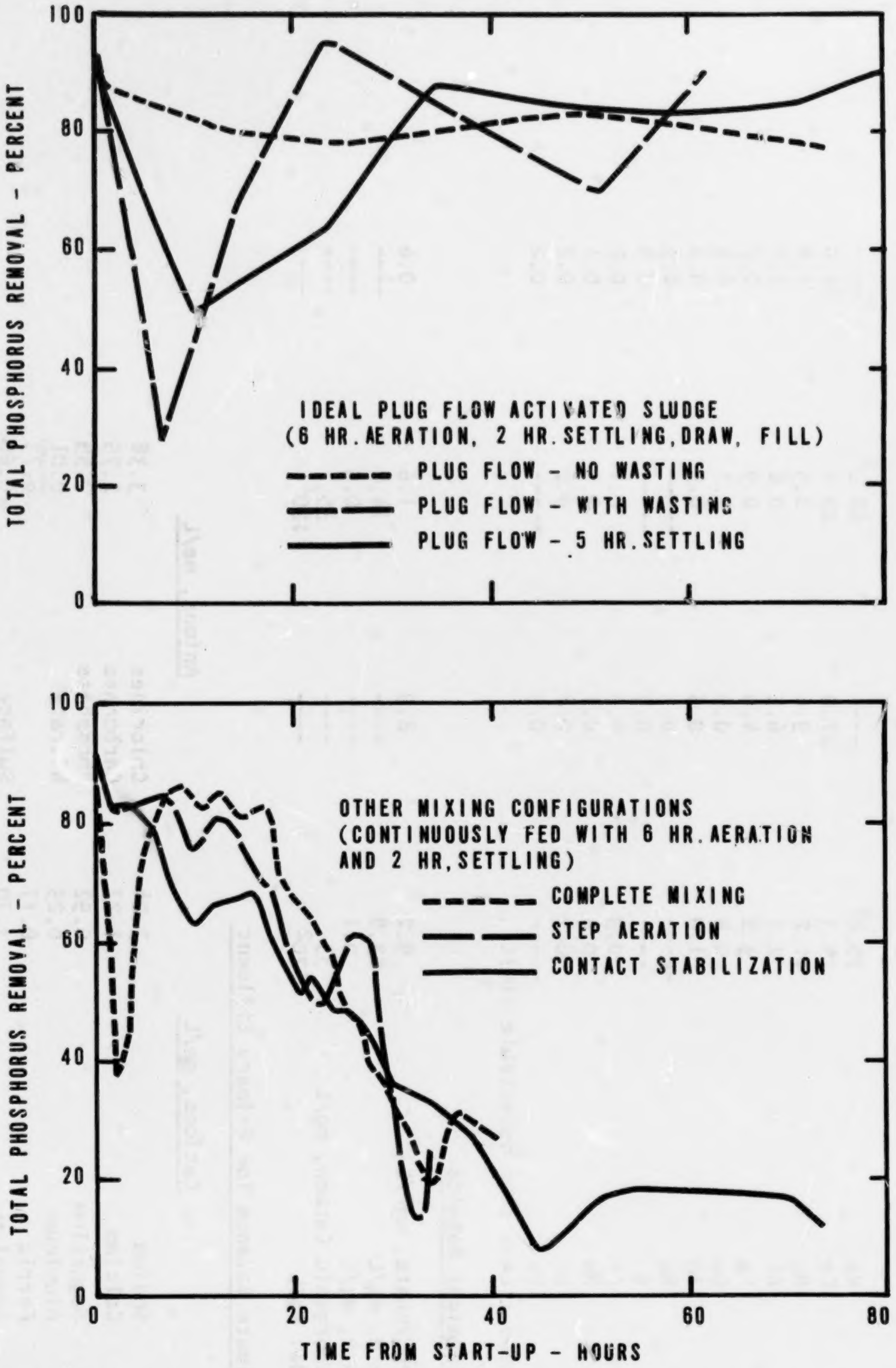
The next laboratory experiment was operation of this laboratory-scale, completely-mixed activated sludge system with its own return sludge (instead of using the full-scale return sludge as was done in the previous test). All laboratory-scale, completely-mixed activated sludge systems with individual recirculation lost the high degree of phosphate removal within 20 to 30 hours of start-up. Operation for a two-week period did not show any indication of improvement of phosphorus removal above 20 percent. A graphical plot of phosphorus removal with time for several typical laboratory-scale studies is presented in Figure 22. Other mixing configurations are included in this test, in addition to complete mixing were step aeration and contact stabilization; a similar loss in phosphorus removal was experienced.

The only laboratory-scale activated sludge studies that maintained a high degree of phosphorus removal for a period up to 80 hours were those performed in an ideal plug-flow system that consisted of batch aeration for 6 hours, settling for 2 hours, and drawing and filling with new primary effluent. These results are shown in the upper portion of Figure 22. In all the studies presented on Figure 22, fresh primary effluent was used as the feed material, and all systems were started up with full-scale return sludge; the initially indicated removal was equivalent to that of the full-scale system at the time of startup. The observations in Figure 22 were made prior to the initiation of the full-scale mixing configuration experiment. Complete data for the studies depicted in Figure 22 are presented in Appendix A (Table A-12).

General Findings

Metal Results

Extensive metal analyses were performed during the phosphorus removal project to aid in the assessment of the contribution of metal precipitation to the phosphorus removal phenomenon. For the Baltimore primary and secondary effluents, average metal ion concentrations and an approximate cation-anion balance are presented in Table 11. This table also gives a comparison between current metal averages and previous observations made by the FWQA that included more parameters than were considered in this project. Average results indicate reasonably typical domestic wastewater characteristics, with fairly low calcium concentrations. These average values indicate greater removal (from primary effluent to secondary effluent) of magnesium ion than of calcium ion. The averages and the cation-anion balances likewise indicate a fairly typical domestic wastewater.



PHOSPHORUS REMOVAL IN LABORATORY SYSTEMS AFTER START UP WITH FULL-SCALE ACTIVATED SLUDGE
FIGURE 22

Table 11

Average Wastewater Metal Content and Anion-Cation Balance

Metal	Primary Effluent 7/14-12/4/69 RFW mg/L	Primary Effluent 5/13-23/1968 FWQA mg/L	Secondary Effluent 7/14-12/4/69 RFW[1] mg/L	Secondary Effluent 5/13-23/1968 FWQA mg/L
Na	70.0[2]	----	68.0[2]	----
Ca	25.3	27.0	23.4	26.0
Mg	11.2	9.6	8.5	7.6
Al	2.1	6.5	0.8	3.0
Fe	3.2	4.0	0.9	0.7
Cu	0.4	0.5	0.1	0.4
Zn	1.0	0.5	0.3	0.5
Ba	-----	0.5	-----	0.5
B	-----	0.4	-----	0.4
Cr	0.9	0.5	0.1	0.2
Mn	0.4	0.1	0.1	0.1
Ni	0.2	0.8	0.2	0.2
Pb	-----	0.5	-----	0.2

All Others - Less than detectable limit

Chemical Results

	Primary Effluent 7/14-12/4/69 RFW	Primary Effluent 5/13-23/1968 FWQA	Secondary Effluent 7/14-12/4/69 RFW[1]	Secondary Effluent 5/13-23/1968 FWQA
Ortho Phosphate, mgP/L	9.2	8.9	1.6	0.6
Ammonia N, mg/L	23.8	----	14.8	----
Nitrate N, mg/L	0.1	----	0.5	----
Total Inorganic Carbon, mg/L	33	----	35	----
Chloride, mg/L	120[2]	----	120[2]	----

Approximate Balance for Primary Effluent

Cations, me/L		Anions, me/L	
Sodium	3.04	Chlorides	3.38
Calcium	1.27	Carbonate	2.75
Magnesium	0.92	Phosphate	0.59
Aluminum	0.23	Nitrate	0.01
			6.73
Ferric	0.17		
Ammonium	1.70	Sulfate (by difference)	0.60
	7.33		7.33

---

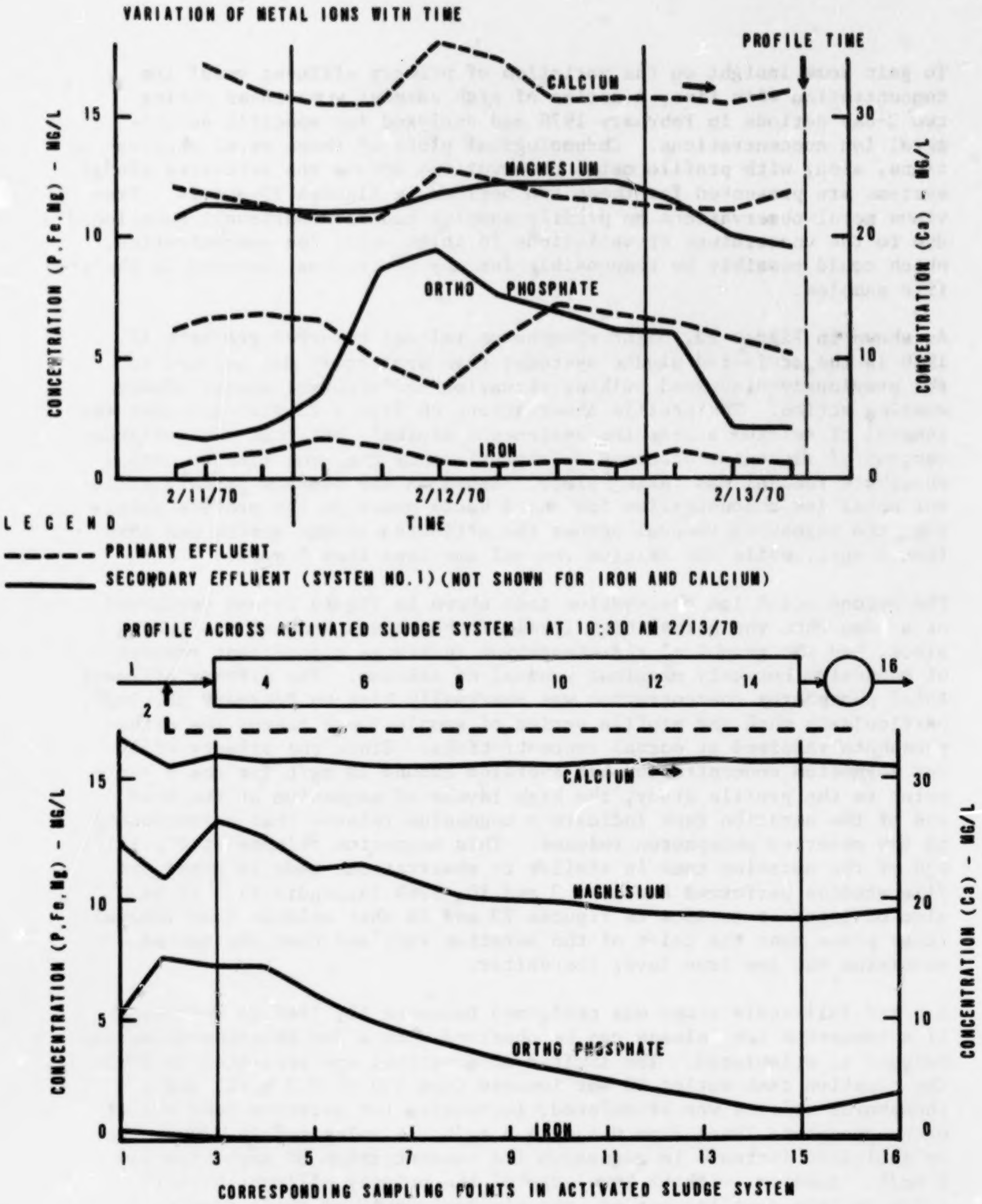
[1] System No. 2.
[2] Based on Limited Number of Analyses.

To gain some insight on the variation of primary effluent metal ion concentration with time, a series of grab samples were taken during two 3-day periods in February 1970 and analyzed for specific soluble metal ion concentrations. Chronological plots of these metal observations, along with profile metal observations across the activated sludge systems are presented for these two periods in Figures 23 and 24. Previous metal observations on profile samples had been seriously questioned due to the uncertainty of variations in inlet metal ion concentration, which could possibly be responsible for any variations observed in the profile samples.

As shown in Figure 23, major phosphorus release occurred February 12, 1970 in the activated sludge systems; this apparently was related to the previously-discussed bulking situation and abnormal excess sludge wasting action. The profile observations on Figure 23 indicate that the removal of calcium across the system was minimal, but that a significant removal of magnesium occurred at approximately the same time as ortho-phosphate removal was taking place. Based on the average primary effluent metal ion concentration for the 6 hours prior to the profile sampling, the magnesium removal across the activated sludge system was more than 2 mg/L, while the calcium removal was less than 1 mg/L.

The second metal ion observation test shown in Figure 24 was performed at a time when the normal high level of phosphorus removal was taking place, and the graphical representation indicates significant removal of magnesium but only marginal removal of calcium. The primary effluent total phosphorus concentration was abnormally high on February 28, 1970, particularly when the profile series of samples were taken; the ortho-phosphate remained at normal concentrations. Since the primary effluent magnesium concentration had averaged around 10 mg/L for the 6 hours prior to the profile study, the high levels of magnesium at the head end of the aeration tank indicate a magnesium release that corresponded to the observed phosphorus release. This magnesium release at the inlet end of the aeration tank is similar to observations made in other profile studies performed December 3 and 10, 1969 (Appendix A). It is also of interest to note in Figures 23 and 24 that soluble iron removal takes place near the inlet of the aeration tank and that the system maintains the low iron level thereafter.

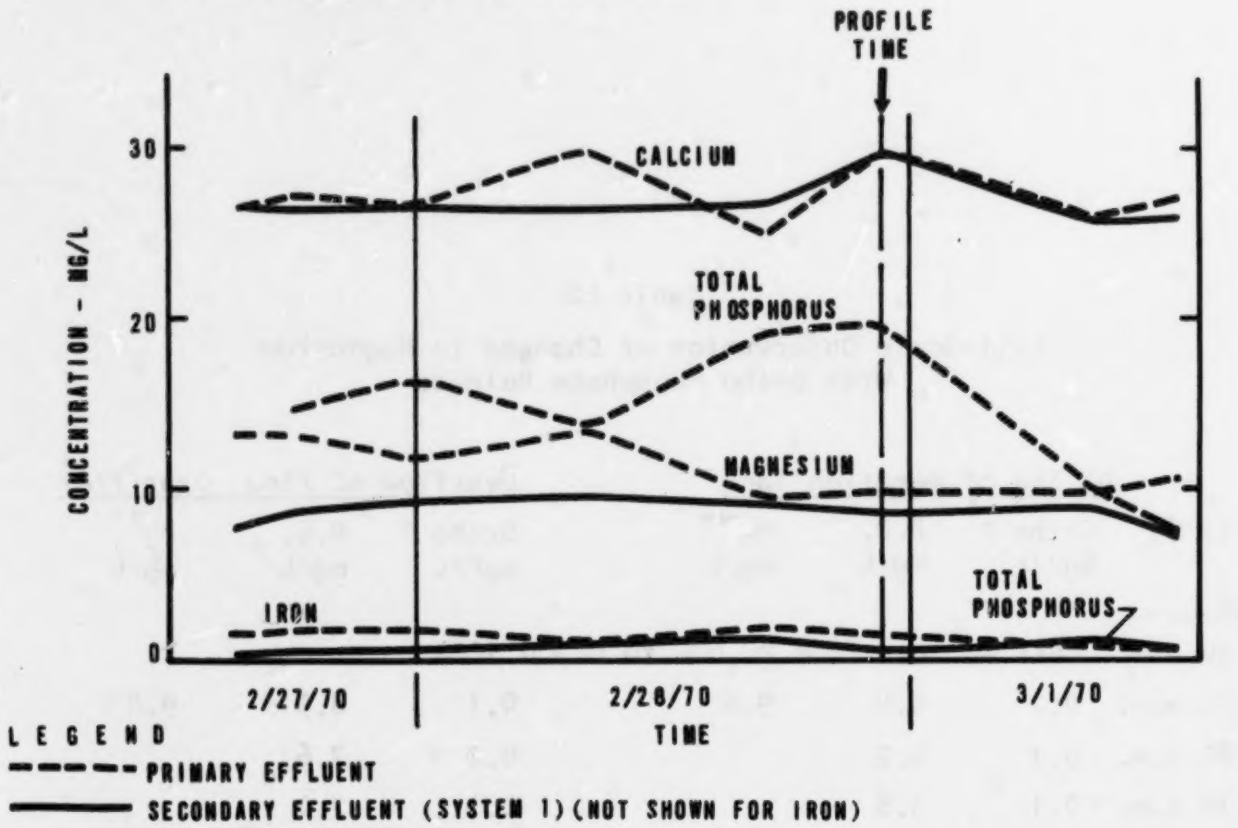
A brief full-scale study was performed December 11, 1969 to determine if a magnesium ion release can be observed when a low DO-ortho-phosphate release is stimulated. The limited observations are presented in Table 12. The aeration tank outlet DO was lowered from 5.0 to 0.7 mg/L, and a phosphorus release was stimulated, increasing the aeration tank outlet ortho-phosphate level from 0.1 to 6.3 mg/L. Simultaneously, there was an indicated increase in magnesium ion concentration of approximately 2 mg/L. However, without knowledge of the primary effluent history prior to this sampling period, the conclusiveness of these results is diminished.



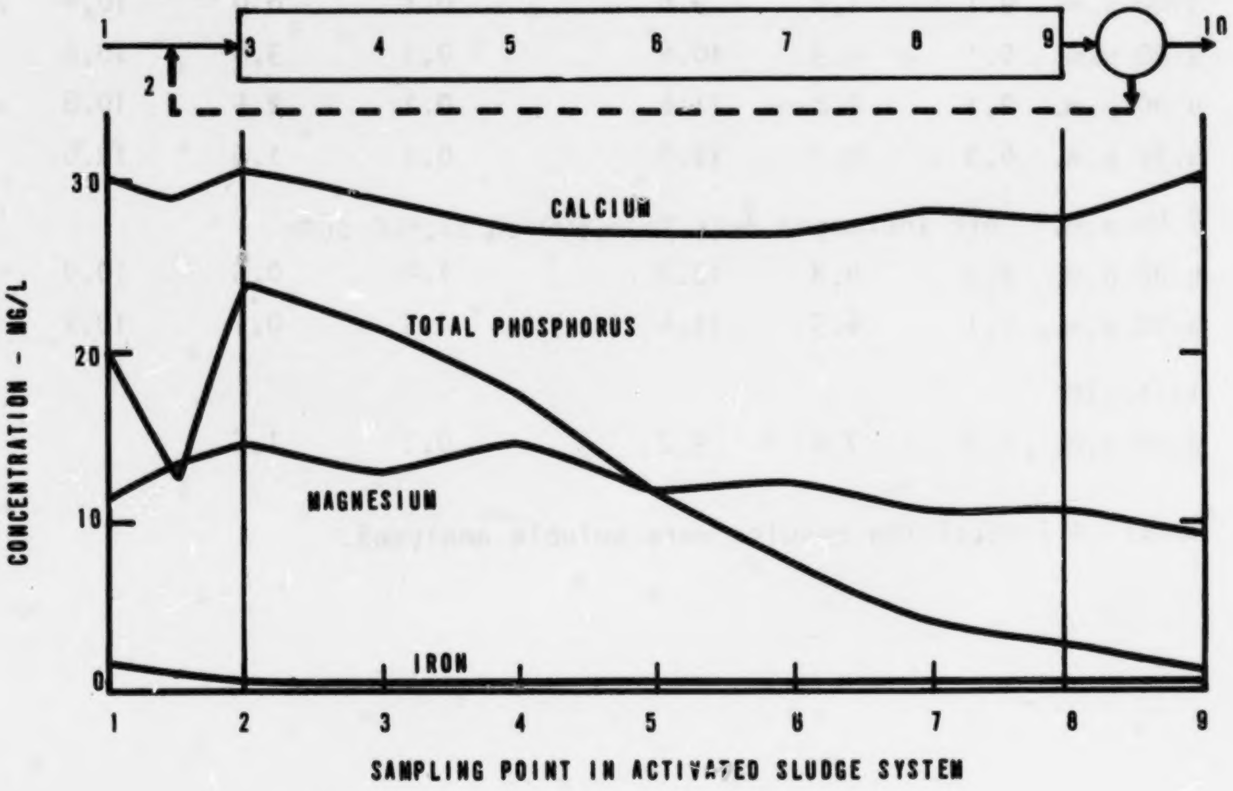
SOLUBLE METAL ION OBSERVATION TEST NO.1

FIGURE 23

VARIATION OF METAL IONS WITH TIME



PROFILE ACROSS ACTIVATED SLUDGE SYSTEM 1 AT 10:30 PM 2/28/70



SOLUBLE METAL ION OBSERVATION TEST NO.2

FIGURE 24

Table 12

Full-Scale Observation of Changes in Magnesium With Ortho Phosphate Release

12/11/69	At End of Aeration Tank			Overflow of Final Clarifier		
Time	Ortho P mgP/L	D.O. mg/L	Mg^{++} mg/L	Ortho P mgP/L	D.O. mg/L	Mg^{++} mg/L
10:30 a.m.	Air Reduced From 20,000 to 6,500 SCFM					
11:00 a.m.	0.1	5.0	9.6	0.1	8.5	9.4
12:00 a.m.	0.1	4.2		0.2	7.6	
1:30 p.m.	0.1	3.8		0.1	7.2	
2:30 p.m.	0.1	3.0		0.1	6.5	
3:00 p.m.	0.1	1.2	9.8	0.1	6.0	10.4
3:30 p.m.	0.1	0.9	10.6	0.1	3.8	10.6
4:00 p.m.	2.1	0.8	11.6	0.1	2.5	10.8
4:30 p.m.	6.3	0.7	12.8	0.1	1.5	10.6
4:45 p.m.	Air Increased Back To 6,500 to 14,500 SCFM					
5:00 p.m.	2.0	4.8	12.2	1.4	0.5	10.8
5:30 p.m.	0.1	6.5	11.4	1.5	0.7	10.2
12/12/70						
9:00 a.m.	0.3	7.0	9.2	0.2	1.5	

Note: All metal ion results were soluble analyses.

As stated previously, weekly samples (involving the different activated sludge sampling points) were composited and subjected to metal analyses, the complete results of which are tabulated in Appendix A (Table A-3). Table 13 is a summary of the average and range of metal content of the activated sludge system composite samples. In Table 14, the metal content of aeration tank mixed liquor is expressed in terms of weight percent of the suspended solids. The overall averages for both the control and test systems are indicated along with selected weekly composited sample results to cover a range of conditions.

The weekly composite metal analyses were also used for a metal accountability study for phosphorus removal determination. Although this is circumstantial and the most optimistic stoichiometric combinations were used, these accountability results are of interest. Detailed results are included in Appendix A (Table A-14), and a summary is presented in Table 15.

In giving credit for biological removal as accounting for one part of phosphorus for every 100 parts BOD_5, the metal ion content of the waste excess return sludge can adequately account for the overall phosphorus removal.

Miscellaneous Laboratory-Scale Tests

Additional limited laboratory-scale tests were performed during the field study to help define the effects of activated sludge on phosphorus removal and to include some of the studies listed in the original contract that could not be performed in the full-scale testing program. A phosphorus removal comparison between full-scale performance and laboratory batch-scale operation is presented in Figure 25. All tests were performed simultaneously on March 1, 1970. The full-scale values were taken at appropriate times from sample points in activated sludge system No. 1, in order to follow the same segment of primary effluent through the system. Although the overall removals were quite comparable for the full-scale and batch observations, the phosphate removal was more rapid in the small, highly aerated laboratory system than in the full-scale system. An additional simultaneous test, shown on Figure 25, was conducted with the primary effluent plus an additional 15 mg P/L of ortho-phosphate. In the 3-hour observation period of this batch test (No. 2), the percentage removal was lower, but a significantly larger absolute quantity of phosphorus was removed.

A brief laboratory test of phosphorus release during long-term aeration was performed, and the results are presented in Figure 26. A continuous-recording pH meter was used for this experiment, and intermittent grab samples were taken. The test was initiated with activated sludge mixed liquor from the control system aeration tank outlet. At the beginning of the test the pH was 7.2, and the soluble total phosphate was 0.2 mg/L. The high level of aeration in the laboratory-scale system resulted in an

Table 13

Summary Of Weekly Composite Metal Analyses
7/14/69 - 12/23/69

Source		Calcium mg/L	Magnesium mg/L	Iron mg/L	Aluminum mg/L	Copper mg/L	Zinc mg/L
Primary Effluent	Avg	25.3	11.2	3.2	2.1	0.4	1.0
	Range	21.8-30.0	8.8-14.2	1.3-6.0	0.8-3.8	0.2-0.9	0.6-1.9
Secondary Effluent (Control No.1)	Avg	23.6	8.1	0.9	0.7	0.1	0.29
	Range	18.6-28.0	6.1-10.7	0.1-2.4	0.5-1.5	<0.1-0.2	0.1-0.5
Secondary Effluent (Test No.2)	Avg	23.2	8.9	0.7	0.8	0.1	0.24
	Range	19.0-25.5	6.5-12.4	0.1-2.1	0.5-3.5	<0.1-0.2	0.1-0.5
Aeration Tank Outlet (Control No.1)	Avg	53.3	30.2	24.6	15.4	3.7	7.8
	Range	31.0-90.0	23.7-40.0	10.3-36.0	5.5-33.0	1.0-5.6	5.5-11.0
Aeration Tank Outlet (Test No.2)	Avg	44.0	28.2	25.3	15.7	3.9	8.0
	Range	27.5-74.0	18.0-48.0	8.8-56.0	4.5-44.0	1.8-7.2	5.5-11.5
Return Sludge (Control No.1)	Avg	118	105	110	78	17	34
	Range	73-168	42-192	43-218	32-133	7-24	19-48
Return Sludge (Test No.2)	Avg	113	90	99	59	17	32
	Range	59-198	37-147	53-190	20-110	8-27	19-40

Note: All samples were analyzed for total metal content.

Table 14

Observations on Metal Content of Activated Sludge at End of Aeration Tank

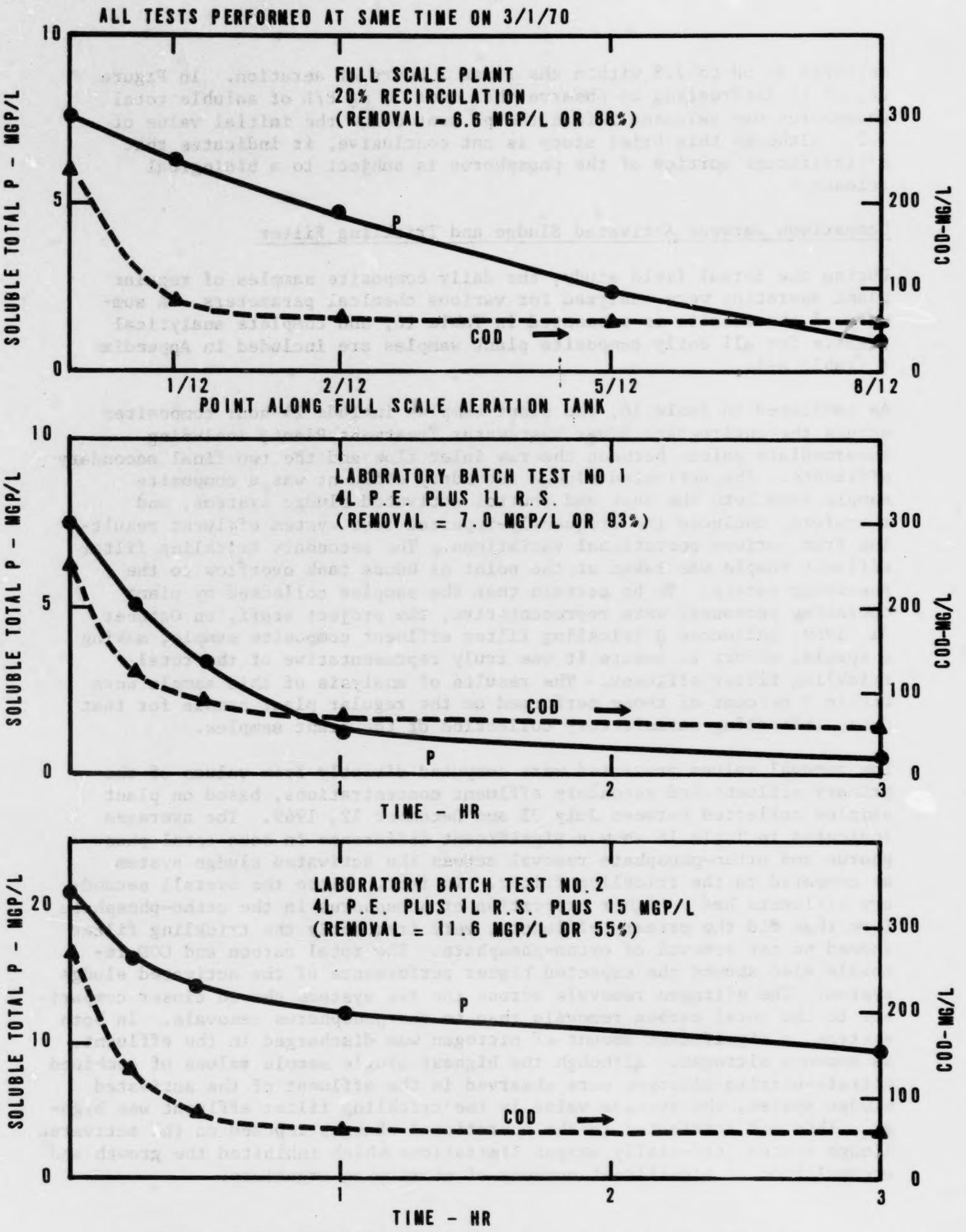
Date	System	Total P Removal Percent	Solids Aeration Tank SS - mg/L	Phosphorus P/SS %	Calcium Ca/SS %	Magnesium Mg/SS %	Iron Fe/SS %	Aluminum Al/SS %	Zinc Zn/SS %	Copper Cu/SS %
7/14-12/4	Avg. No. 1	75	2,070	4.5	1.5	1.1	1.1	0.71	0.36	0.17
7/14-12/23	Avg. No. 2	66	1,980	4.2	1.1	1.0	1.2	0.75	0.39	0.19
8/4-8/69	Avg. No. 1	69	2,150	3.7	2.7	1.0	1.1	0.64	0.34	0.18
8/4-8/69	Avg. No. 2	67	1,450	3.7	2.7	1.3	1.3	0.65	0.53	0.15
9/2-5/69	Avg. No. 1	82	2,270	5.0	-	1.4	1.7	1.4	0.39	0.22
9/2-5/69	Avg. No. 2	85	3,040	4.5	-	1.3	1.2	1.4	0.37	0.23
10/7-10/69	Avg. No. 1	72	1,870	4.1	0.67	0.93	1.1	1.0	0.38	0.29
10/7-10/69	Avg. No. 2	87	1,810	5.1	0.40	1.10	1.2	2.0	0.41	0.28
10/28-31/69	Avg. No. 1	92	1,970	4.9	1.8	1.4	1.2	0.79	0.26	0.06
10/18-31/69	Avg. No. 2	39	1,920	2.6	1.3	-	1.1	0.46	0.27	0.09
12/18-23/69	Avg. No. 2	32	1,620	4.3	1.9	1.0	1.7	0.77	-	-
2/28/70	Grab No. 1	95	1,860	4.5	2.1	0.9	1.5	-	-	-

Note: Metal results are total content analyses.

Table 15

Average of Computations on Theoretical Accountability for Observed Phosphorus Removal

	Control System (7/14 - 12/6/60)	Test System (7/14 - 12/22/69)
Average System Performance		
Phorphorus Removal, Percent	79	66
Phorphorus Removal, mg P/L	8.8	7.3
Accountability Efforts:		
Minimum Biological Requirements, mg P/L (Based on P/BOD_5 Removed = 0.01)	1.5	1.5
Possible Metal Removal (Average Value)		
Calcium (Assume P/Ca = 0.52), mg P/L	1.4	1.4
Magnesium (Assume P/Mg = 0.86), mg P/L	2.7	2.4
Iron (Assume P/Fc = 0.55), mg P/L	1.3	1.5
Aluminum (Assume P/Al = 1.14), mg P/L	1.7	1.5
Copper (Assume P/Ca = 0.48), mg P/L	0.1	0.1
Zinc (Assume P/Zn = 0.47), mg P/L	0.3	0.4
Total (Average From Appendix Table A-14)	9.0	8.8
Difference	+0.2	+1.5



PHOSPHORUS REMOVAL COMPARISON BETWEEN FULL-SCALE AND LABORATORY TESTS

FIGURE 25

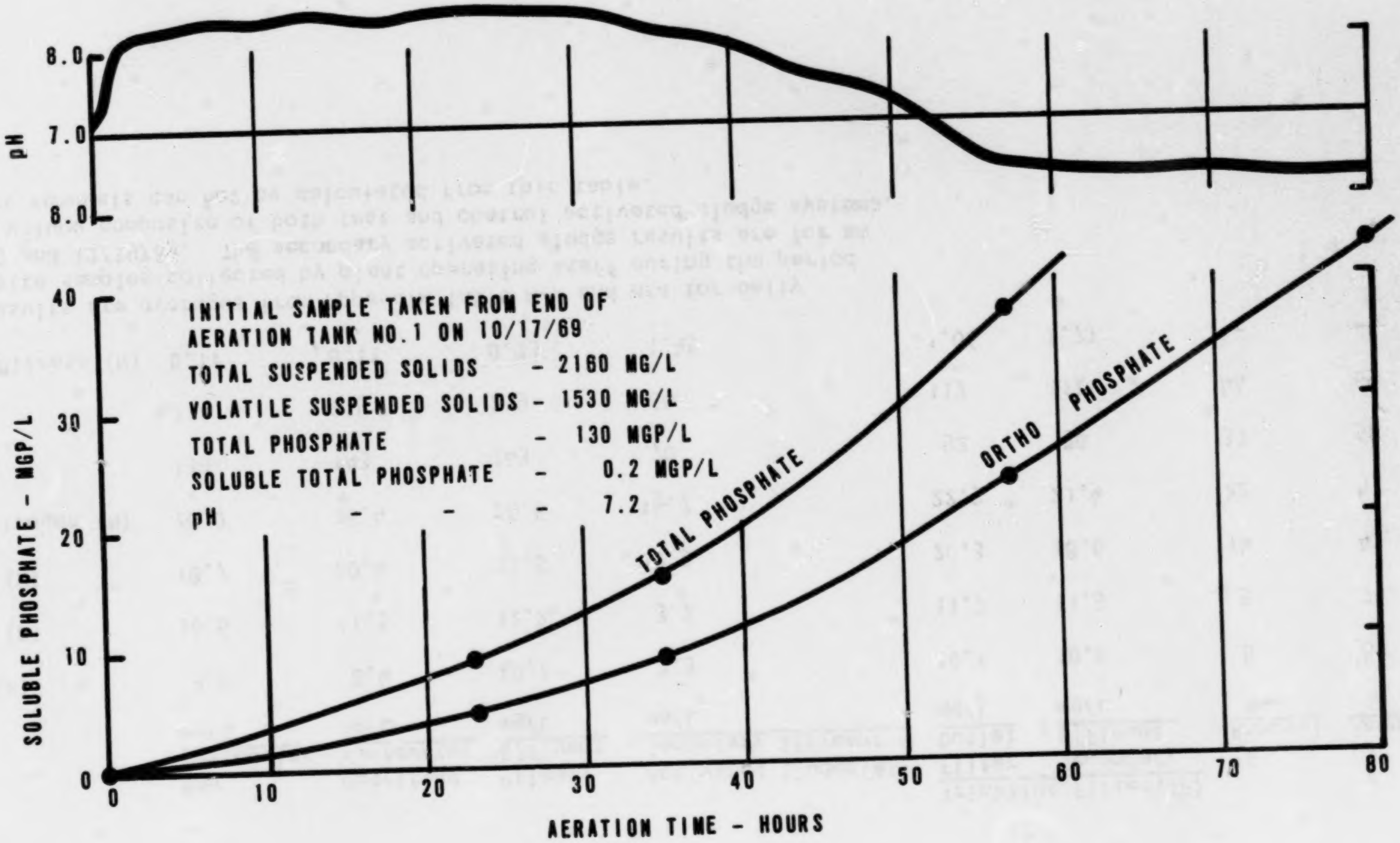
increase in pH to 7.8 within the first 2 hours of aeration. In Figure 26, it is interesting to observe that over 30 mg P/L of soluble total phosphorus was released before the pH went below the initial value of 7.2. Although this brief study is not conclusive, it indicates that a significant portion of the phosphorus is subject to a biological release.

Comparison Between Activated Sludge and Trickling Filter

During the formal field study, the daily composite samples of regular plant operation were analyzed for various chemical parameters. A summary of the results is presented in Table 16, and complete analytical results for all daily composite plant samples are included in Appendix A (Table A-4).

As indicated in Table 16, the plant samples include 24-hour composites across the entire Back River Wastewater Treatment Plant, including intermediate points between the raw inlet flow and the two final secondary effluents. The activated sludge secondary effluent was a composite sample from both the test and control activated sludge systems, and therefore, included the frequently-impaired test system effluent resulting from various operational variations. The secondary trickling filter effluent sample was taken at the point of humus tank overflow to the receiving waters. To be certain that the samples collected by plant operating personnel were representative, the project staff, on October 31, 1969, collected a trickling filter effluent composite sample, making a special effort to assure it was truly representative of the total trickling filter effluent. The results of analysis of this sample were within 5 percent of those performed on the regular plant sample for that date, indicating satisfactory collection of the plant samples.

The removal values presented were computed directly from values of the primary effluent and secondary effluent concentrations, based on plant samples collected between July 31 and December 12, 1969. The averages indicated in Table 16 show a significant difference in both total phosphorus and ortho-phosphate removal across the activated sludge system as compared to the trickling filter. In fact, since the overall secondary effluents had a higher proportion of phosphorus in the ortho-phosphate form than did the primary effluents, very frequently the trickling filter showed no net removal of ortho-phosphate. The total carbon and COD removals also showed the expected higher performance of the activated sludge system. The nitrogen removals across the two systems showed closer comparison to the total carbon removals than to the phosphorus removals. In both systems, a significant amount of nitrogen was discharged in the effluent, as ammonia nitrogen. Although the highest single sample values of combined nitrate-nitrite nitrogen were observed in the effluent of the activated sludge system, the average value in the trickling filter effluent was higher. This was attributed to the operational changes imposed on the activated sludge system, especially oxygen limitations which inhibited the growth and accumulation of significant numbers of nitrifying organisms.



LABORATORY TEST OF PHOSPHATE RELEASE ON LONG TERM AERATION

FIGURE 26

Table 16

Summary Of Comparison Between
Activated Sludge And Trickling Filter Performance

Analysis	Raw Wastewater mg/L	Degritted Wastewater mg/L	Primary Effluent mg/L	Activated Sludge(AS) Secondary Effluent mg/L	Trickling Filter(TF) Filter Outlet mg/L	Trickling Filter(TF) Secondary Effluent mg/L	TF Removal %	AS Removal %
Ortho Phosphate (P)	8.0	8.4	10.2	2.3	10.1	10.0	8	81
Total Phosphorus (P)	10.6	11.3	12.2	3.2	11.7	11.5	9	74
Ammonia Nitrogen (N)	18.7	20.4	22.6	12.9	20.3	18.6	14	42
Total Kjeldahl Nitrogen (N)	26.0	28.4	26.6	14.7	22.9	21.4	22	47
Total Carbon (C)	139	143	143	70	92	90	37	50
COD	211	219	219	64	117	112	46	69
Combined Nitrite-Nitrate (N)	0.11	0.11	0.23	1.45	1.06	1.71	--	--

Note: All results are averages from Appendix Table A-4 and are for daily composite samples collected by plant operating staff during the period 8/1/69 and 12/19/69. The secondary activated sludge results are for an equal volume composite of both test and control activated sludge systems. Percent removals can not be calculated from this table.

Correlations of Wastewater Characteristics

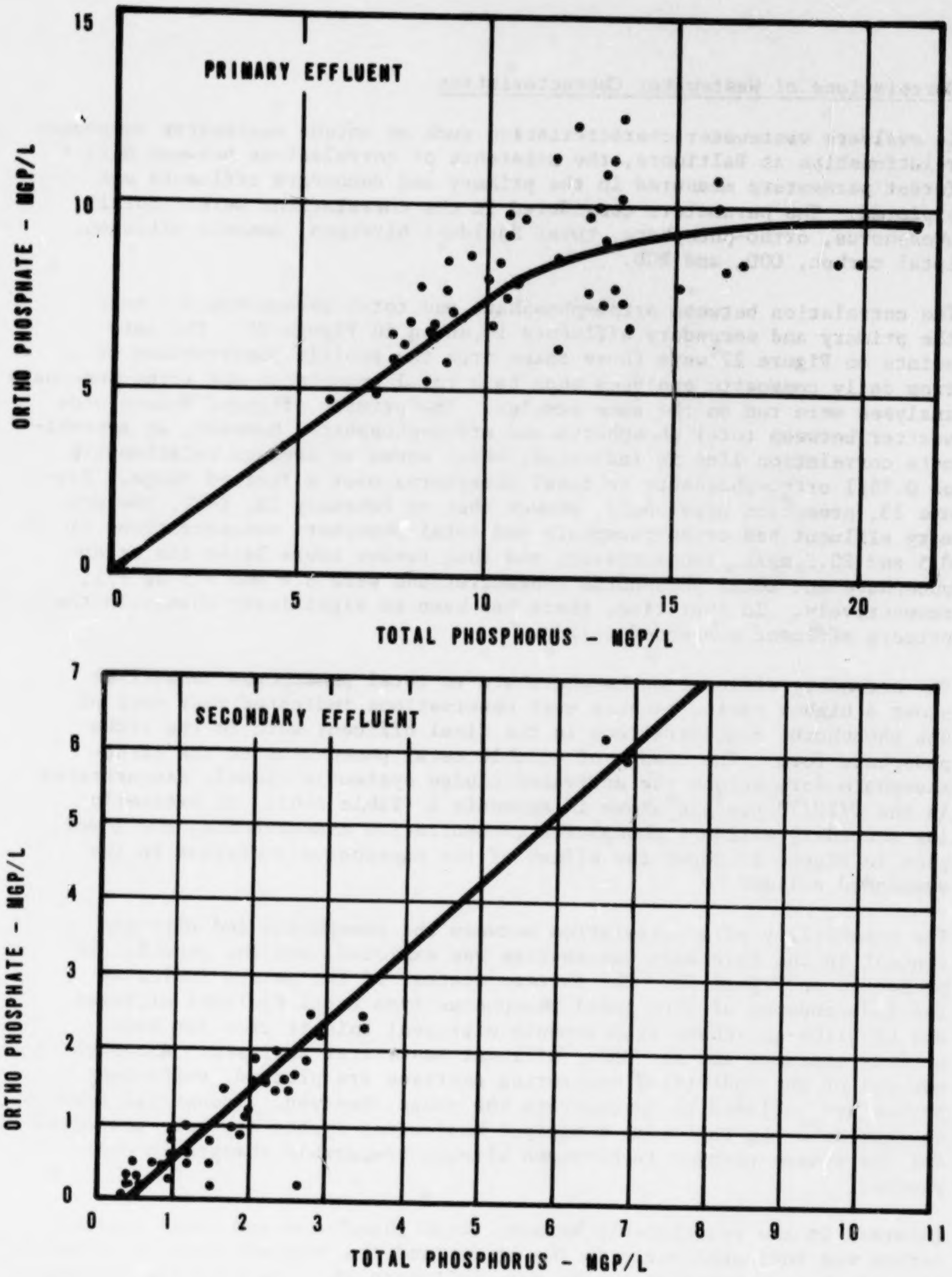
To evaluate wastewater characteristics such as unique wastewater component relationships at Baltimore, the existence of correlations between different parameters measured in the primary and secondary effluents was explored. The parameters considered in the correlations were: total phosphorus, ortho-phosphate, total Kjeldahl nitrogen, ammonia nitrogen, total carbon, COD, and BOD.

The correlation between ortho-phosphate and total phosphorus for both the primary and secondary effluents is shown in Figure 27. The data points on Figure 27 were those taken from the profile observations or from daily composite analyses when both total phosphorus and ortho-phosphate analyses were run on the same samples. The primary effluent showed wide scatter between total phosphorus and ortho-phosphate; however, an approximate correlation line is indicated, which shows an average relationship of 0.75/1 ortho-phosphate to total phosphorus over a limited range. Figure 23, presented previously, showed that on February 28, 1970, the primary effluent had ortho-phosphate and total phosphate concentrations of 8.5 and 20.5 mg/L, respectively, and that twelve hours later the ortho-phosphate and total phosphorus concentrations were 8.4 and 9.5 mg P/L, respectively. In that time, there had been no significant change in the primary effluent suspended solids.

The secondary effluent ortho-phosphate to total phosphorus comparison shows a higher ratio, because most observations indicated that most of the phosphorus concentrations in the final effluent were in the ortho-phosphate form. The change of soluble total phosphorus to the ortho-phosphate form across the activated sludge system is clearly demonstrated in the 2/28/70 profile shown in Appendix A (Table A-6). At extremely low secondary effluent phosphorus concentration measurements, the lower plot in Figure 27 shows the effect of the phosphorus contained in the suspended solids.

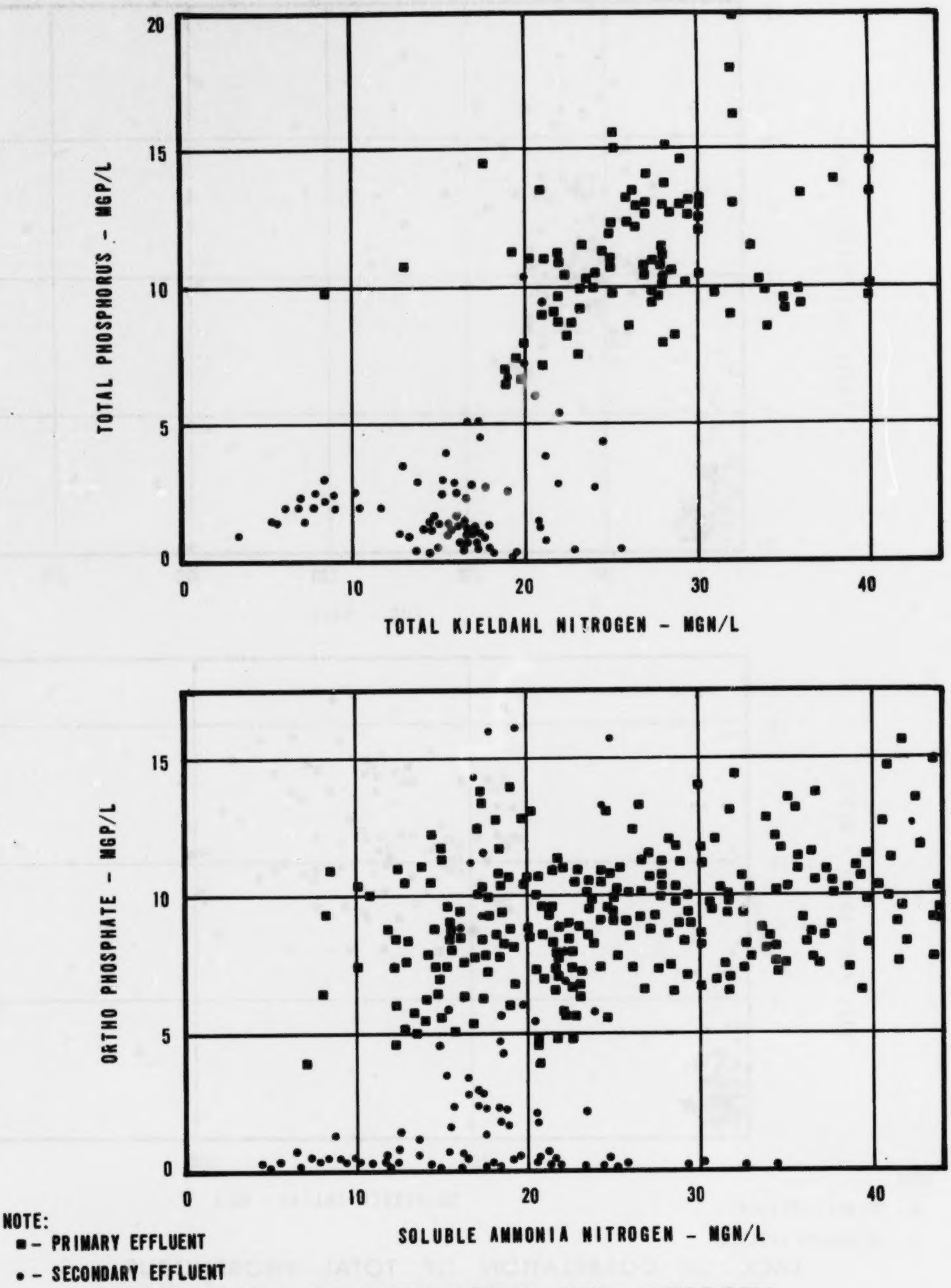
The possibility of a correlation between the phosphorus and nitrogen content in the Baltimore wastewaters was explored, and the results are presented on Figure 28. The extreme scatter of the points indicates the independence of both total phosphorus from total Kjeldahl nitrogen and of ortho-phosphate from ammonia nitrogen; this is true for both primary effluent and secondary effluent wastewater analyses. Although not all of the individual monitoring analyses are plotted, sufficient points are included to demonstrate the range observed. Industrial discharges into the Baltimore municipal wastewater system may have accounted for the severe changes in nitrogen without comparable changes in phosphorus.

Interest in the relationship between total phosphorus and total organic carbon was indicated early in the study, and the apparent lack of correlation of these parameters can be seen in Figure 29. The possible correlation between total phosphorus and suspended solids for both primary



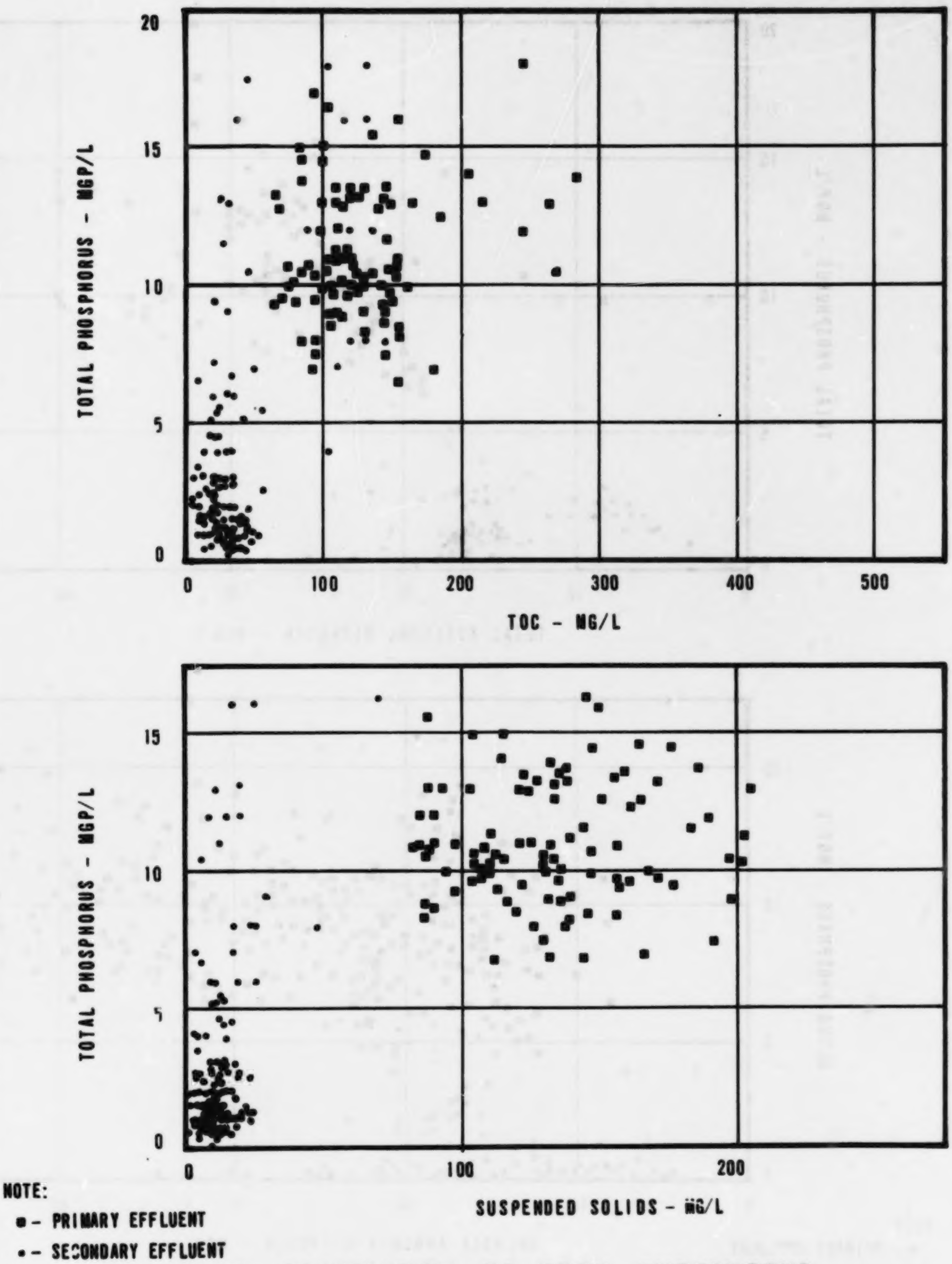
CORRELATION BETWEEN ORTHO AND TOTAL PHOSPHATE

FIGURE 27



INDEPENDENCE OF PHOSPHORUS AND NITROGEN IN BALTIMORE WASTEWATER

FIGURE 28



LACK OF CORRELATION OF TOTAL PHOSPHORUS WITH TOC AND SUSPENDED SOLIDS

FIGURE 29

effluent and secondary effluent is also shown in Figure 29. The releases of phosphates that occurred in the secondary effluent apparently were not associated with either the total organic carbon or suspended solids concentrations.

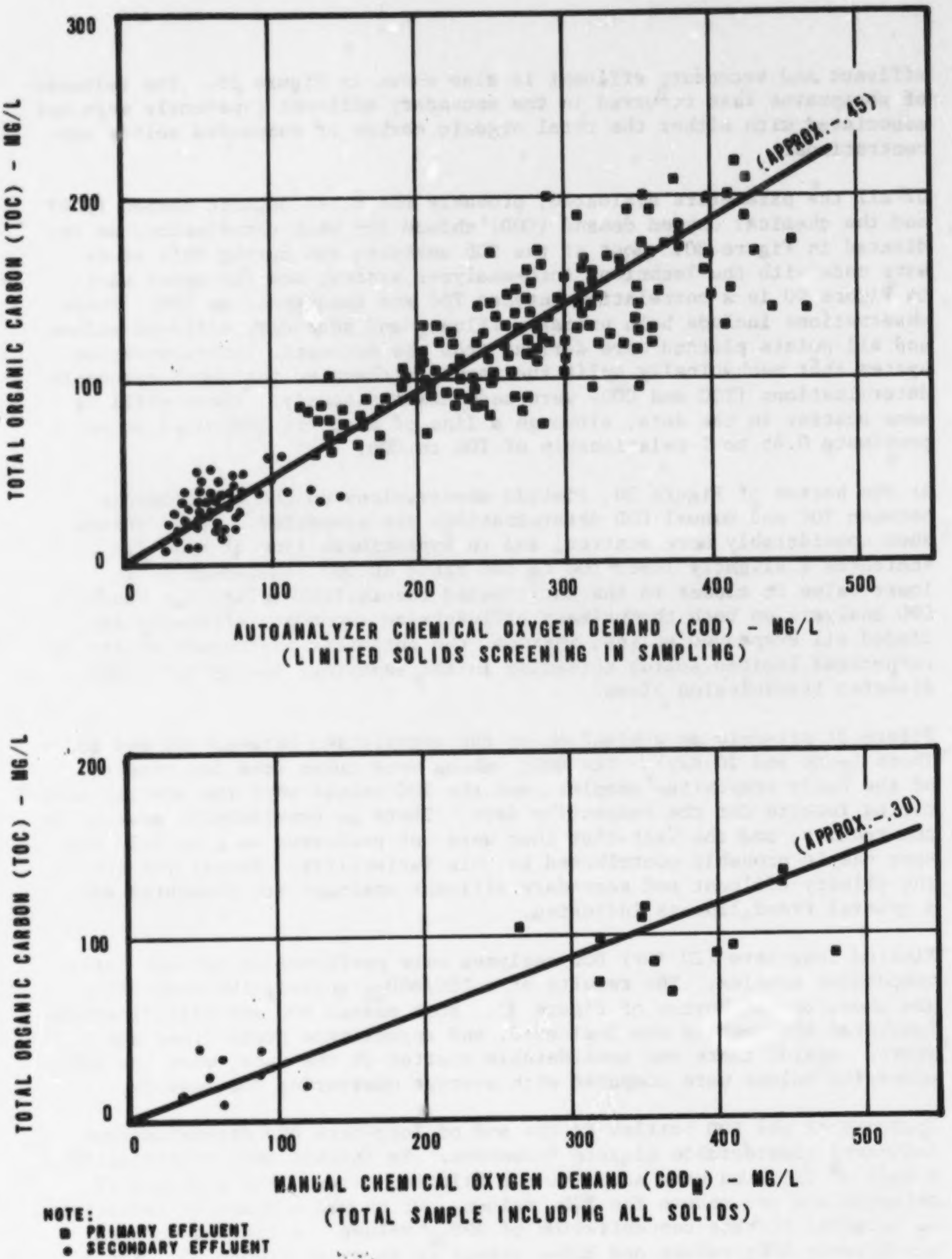
Of all the parameters evaluated, probably the total organic carbon (TOC) and the chemical oxygen demand (COD) showed the best correlation, as indicated in Figure 30. Most of the COD analyses run during this study were made with the Technicon Auto-analyzer system, and the upper plot in Figure 30 is a correlation between TOC and Auto-analyzer COD. These observations include both primary effluent and secondary effluent values and all points plotted were derived from the automatic instrumentation system that mechanically split the sample streams so that both automatic determinations (TOC and COD) were made simultaneously. There still is some scatter in the data, although a line of best fit indicates an approximate 0.45 to 1 relationship of TOC to COD.

At the bottom of Figure 30, limited observations on the relationship between TOC and manual COD determinations are presented. These points show considerably more scatter, and an approximate line of best fit indicates a slightly lower TOC to COD ratio (0.30). Although this lower value is closer to the anticipated theoretical value, the manual COD analysis on both the primary effluent and secondary effluents included all suspended solids; whereas, the automatic instrument system incorporated limited solids screening in the sampling, due to the small-diameter transmission lines.

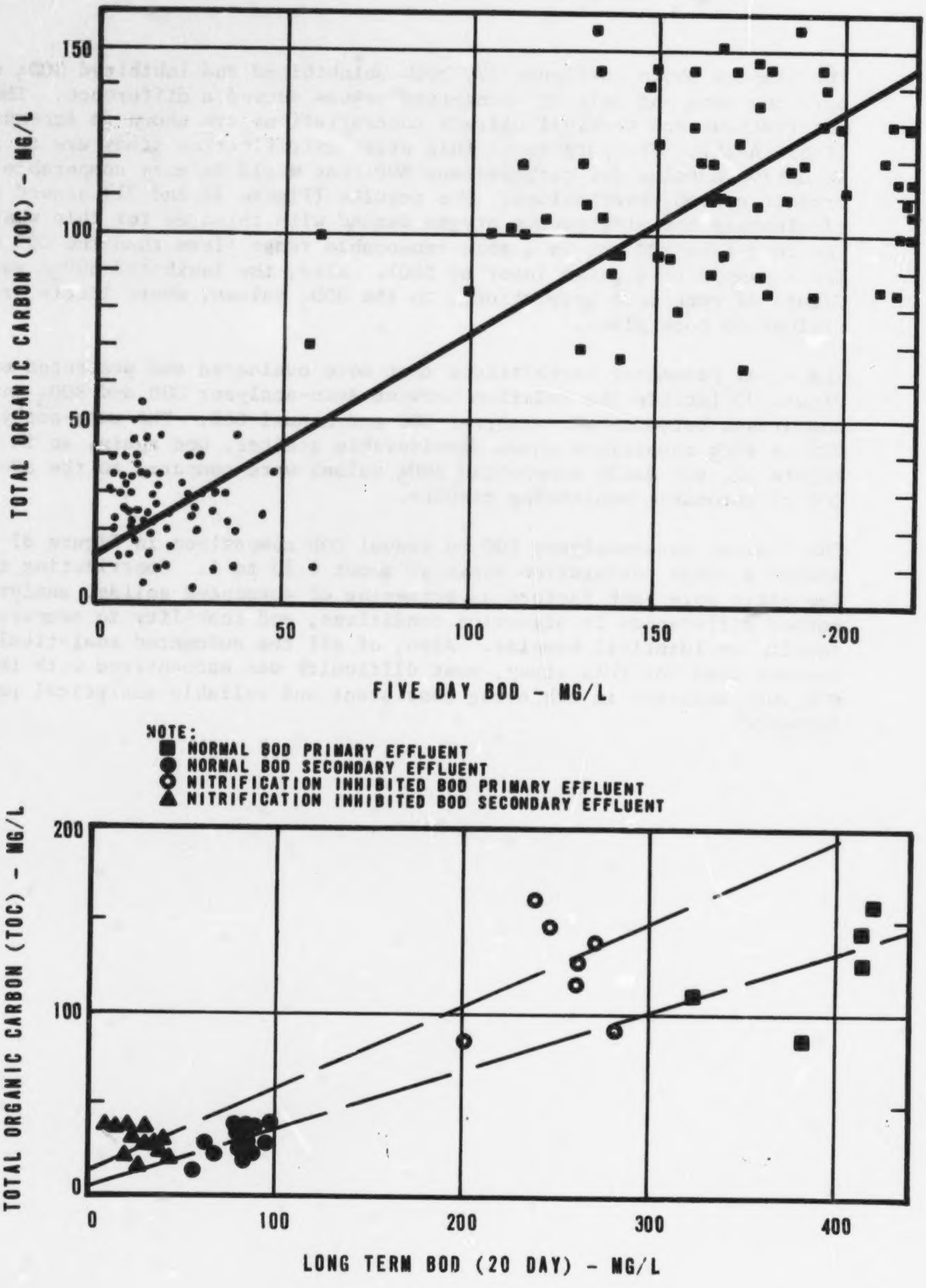
Figure 31 presents an evaluation of the correlation between TOC and BOD (both 5-day and 20-day). The BOD5 values were taken from the results of the daily composites samples, and the TOC values were the average monitoring results for the respective days. There is considerable scatter in the results, and the fact that they were not performed on precisely the same sample probably contributed to this variability. Points for both the primary effluent and secondary effluent analyses are presented and a general trend line is indicated.

Limited long-term (20-day) BOD analyses were performed on certain daily composites samples. The results of a TOC/BOD$_{20}$ correlation evaluation are shown on the bottom of Figure 31. Both normal BOD and nitrification-inhibited BOD results are indicated, and approximate trend lines are shown. Again, there was considerable scatter in the data, when the BOD composite values were compared with average monitoring TOC results.

Analysis of the BOD bottles at the end of long-term BOD determinations indicated considerable nitrate formation. To inhibit this nitrification, 5 mg/L of thiourea were added to the dilution water. The presence of thiourea did not reduce the BOD$_5$ values, but showed a dramatic reduction of terminal nitrate concentration of BOD$_{20}$ values. A limited comparison between BOD5 values and BOD$_{20}$ values is shown on Figure 32. For all



CORRELATION BETWEEN TOC AND COD
FOR PRIMARY AND SECONDARY EFFLUENT
FIGURE 30



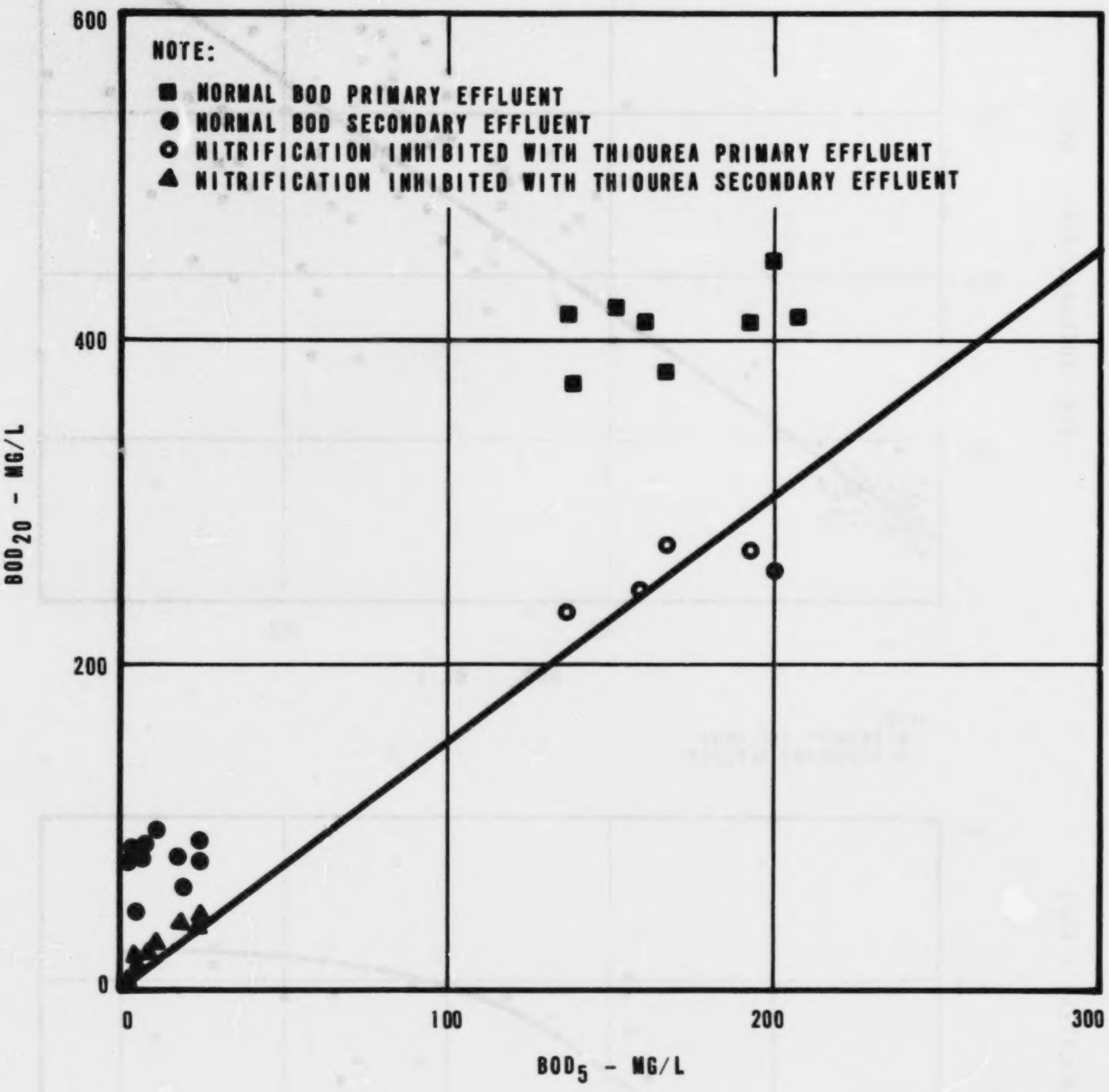
CORRELATION BETWEEN TOC AND BOD
FOR DAILY COMPOSITES OF PRIMARY AND SECONDARY EFFLUENT

FIGURE 31

the samples shown in Figure 32, both uninhibited and inhibited BOD_5 values were the same and only the long-term values showed a difference. The actual observations and terminal nitrate concentrations are shown in Appendix A (Table A-15). The purpose of this brief nitrification study was to attempt to derive a value for carbonaceous BOD that would be more comparable to total organic carbon observations. The results (Figure 30 and 31) showed that by eliminating the nitrogenous oxygen demand with thiourea for this wastewater, the long-term BOD was in a more reasonable range (less than the COD value for a sample of a given level of TOC). Also, the inhibited BOD_{20} value in Figure 32 were more proportional to the BOD_5 values, where little or no nitrification took place.

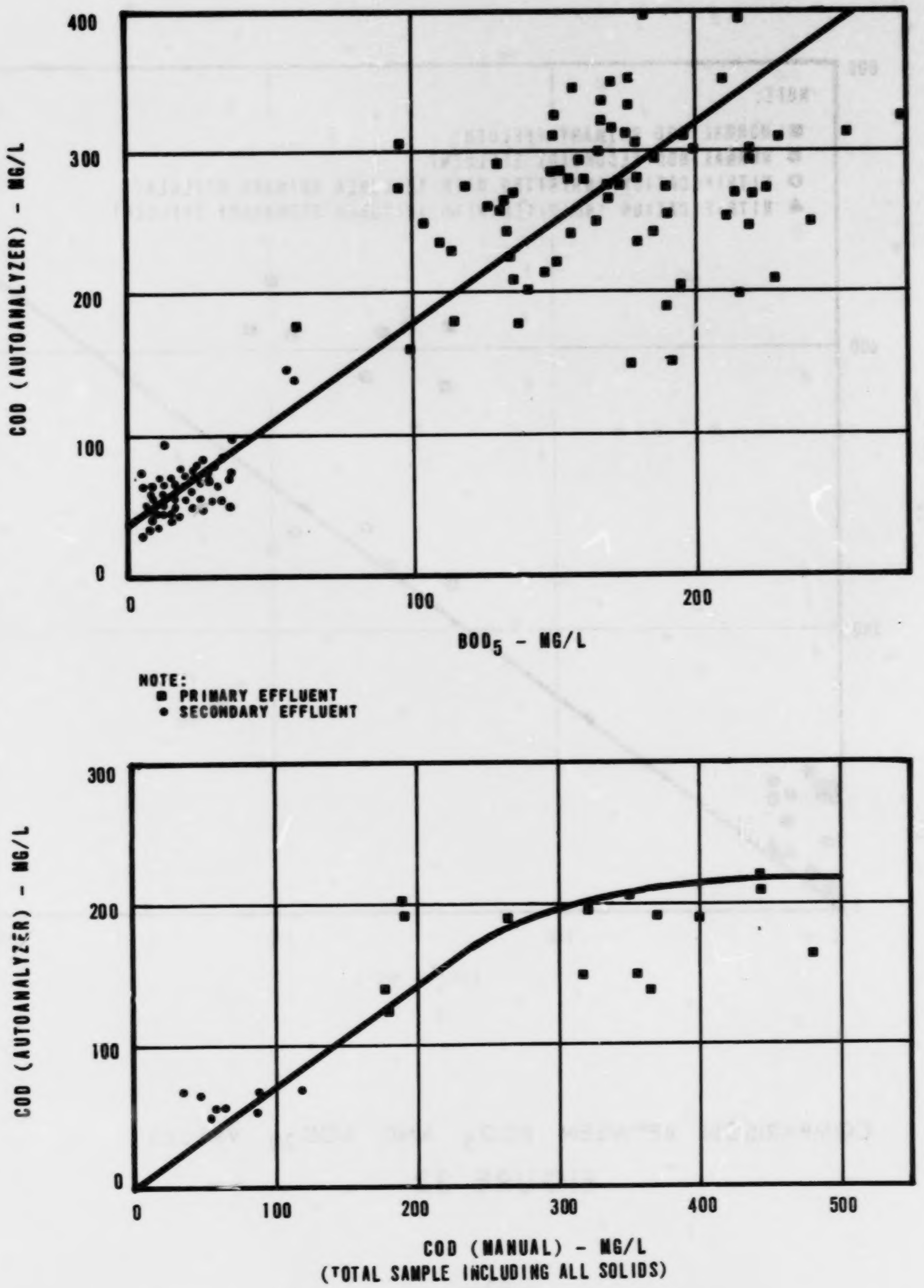
The final parameter correlations that were evaluated and presented on Figure 33 include the relation between Auto-analyzer COD and BOD_5 and a comparison between auto-analyzer COD and manual COD. The auto-analyzer COD to BOD_5 comparison shows considerable scatter, and again, as in Figure 31, the daily composited BOD_5 values were compared to the average COD of automatic monitoring results.

The limited auto-analyzer COD to manual COD comparison in Figure 31 showed a rough correlation ratio of about 0.70 to 1. Contributing to this low ratio were such factors as screening of suspended solids, analytical method differences in digestion conditions, and inability to compare results on identical samples. Also, of all the automated analytical systems used for this study, most difficulty was encountered with the COD auto-analyzer in achieving consistent and reliable analytical performance.



COMPARISON BETWEEN BOD_5 AND BOD_{20} VALUES

FIGURE 32



CORRELATION BETWEEN AUTOANALYZER COD AND MANUAL COD AND BOD$_5$

FIGURE 33

SECTION IV

DISCUSSION OF EXPERIMENTAL RESULTS

Demonstration of Full-Scale Activated Sludge Phosphate Removal

Analytical results of process performance have demonstrated on a long-term basis that the activated sludge portion of the Back River Wastewater Treatment Plant is capable of providing a consistently high degree of phosphorus removal. Observations have shown that this removal is not dependent upon the seasons and occurs consistently throughout the year. One important aspect of activated sludge phosphorus removal is disposal of the phosphorus contained in the waste activated sludge, which comprises the net removal of the system. At Baltimore, this is accomplished by pumping the waste activated sludge back to the primary clarifiers, from which it was distributed throughout the total plant flow. Approximately 12 percent of any subsequently-released phosphorus returned to the activated sludge system, the remainder going to the trickling filter system. Therefore, the overall net phosphorus removal of the combined activated sludge and trickling filter at the Baltimore Back River Wastewater Treatment Plant was not significantly higher than that observed at other municipal wastewater treatment plants, because there was no terminal disposal for phosphorus. The phosphorus from the abnormally high removal in the activated sludge system was subsequently discharged through the trickling filter system.

Continuous monitoring data collected during the four-month period from August to December 1969 on the control portion of the activated sludge system indicated that total phosphorus removals were 73 percent or greater 90 percent of the time. It should be pointed out that the control activated sludge system was operated at previously-evolved normal plant conditions and not necessarily at conditions selected as optimum for phosphorus removal. During this period, the secondary effluent from the control system had a total phosphorus content of below 2.7 mg P/L 90 percent of the time. The total phosphorus content of the activated sludge generally was between 2 and 5 percent, and since the suspended solids concentration of the secondary effluent normally was between 10 and 30 mg/L, it appears that a major portion of the phosphorus in the final effluent can be attributed to that contained in the suspended solids.

Part of this full-scale demonstration was the development and use of an automatic sampling and analytical system to provide continuous monitoring data and immediate knowledge of plant performance. Such a system was developed, and the overall effectiveness for the survey period resulted in valid instrumental data monitoring 87 percent of the time. Standards were automatically introduced to the monitoring system on a definite schedule to assure validity of the analytical measurements.

Definition of Activated Sludge Phosphorus Removal

Dissolved Oxygen

Oxygen limiting conditions in the aeration tank were found to be a critical parameter in maintaining the phosphorus removal at Baltimore. Although a critical concentration of dissolved oxygen was not defined, observations indicated that when the dissolved oxygen level at the end of the aeration tank dropped below 2.0 to 3.0 mg/L, conditions in the system became such that a rapid release of ortho-phosphate took place in the secondary effluent. When adequate aeration was resupplied to the system, a rapid recovery of phosphorus removal was achieved. In the conventional plug-flow activated sludge system at Baltimore, a D.O. level of 2.0 to 3.0 mg/L at the end of the aeration tank occurs with significantly lower D.O. levels at other points in the aeration tank. Therefore, the Baltimore system normally operated with 0.5 mg/L D.O. in the entire first half of the aeration tank, which increased oxygen transfer efficiency. During most of the year, a moderate aeration level of 1.2 scfm of air per gallon of wastewater was adequate for phosphorus removal.

In every case where a phosphorus release was caused by a low D.O. condition at the end of the aeration tank, the removal of total organic carbon across the system was impaired. Effective phosphorus removal only occurred when oxygen was not limiting and efficient carbon removal was occurring. Oxidation reduction potential (ORP) data showed distinct variations when phosphorus releases were stimulated by low D.O. conditions in the aeration tank. However, in comparisons of observed responsiveness, D.O. measurement at the end of aeration tank was more sensitive than ORP to any changes in aeration that stimulated a phosphorus release.

Suspended Solids

Aeration tank suspended solids concentration (and variations thereof) is another parameter important in the definition of activated sludge phosphorus removal. The full-scale data collected during this project do not rigorously define the critical minimum suspended solids concentration necessary for high phosphorus removal. Aeration tank suspended solids level in the 1,200-3,700 mg/L range did not affect phosphorus removal; however, very limited data indicated that suspended solids in the 600-900 mg/L range may have impaired the phosphorus removal.

The rate of wasting of excess activated sludge appeared to be a very important factor. Rapid wasting of activated sludge creating a significant change in the suspended solids inventory over a short period of time appeared to upset the process, and temporarily impaired the degree of phosphorus removal. This occurrence was observed on at least four occasions during the field study. The quantity of suspended solids in the secondary clarifier, reflected by the depth of sludge blanket, ranging from 1 to 11 feet deep, did not appear to have any negative effect on the phosphorus removal. However, the Baltimore activated sludge system secondary clarifiers have comparatively efficient sludge-removal mechanisms, and most of the time there was very little sludge in the clarifier due to 25 percent recycle, so that little long-term data were collected on blanket fluctuations.

Mixing Configuration

Mixing configuration evaluation was a very important part of the definition studies. The conventional activated sludge aeration tanks at Baltimore have many design features that maximize the occurrence of plug flow, and tracer-study responses clearly demonstrate the existence of this flow condition. Samples taken across the length of the activated sludge system during normal operation showed a phosphorus profile of a distinct release in the first part of the aeration tank followed by an uptake region downstream in the system. Limited modifications of the full-scale system toward complete mixing were inconclusive because no significant departure from plug flow was achieved. Full-scale studies with the activated sludge system modified toward step aeration showed reduced phosphorus removal after the aeration tank mid-point, where the second addition of primary effluent took place. However, recovery to a high level of phosphorus removal was rapid when the systems were restored to plug flow. Modification of the same system to contact stabilization for a brief study period resulted in an even greater impairment in phosphorus removal.

Reported laboratory-scale continuous activated sludge tests using the mixing configurations of complete mixing, step aeration, and contact stabilization were unsuccessful in maintaining the high degree of phosphorus removal. Phosphorus removal was maintained for a 3-day period with a crude draw and fill laboratory system. However, there is a need for developing a satisfactory continuous laboratory system that has the necessary plug flow configuration and has operating characteristics that duplicate the consistent full-scale phosphorus removal observed at Baltimore.

Flow

Definition studies of flow and observations on organic loading indicated no adverse effects on phosphorus removal within the scope of conditions included in the study. Constant operation, which included aeration tank detention times, ranging from 2.5 to 12.0 hours, and diurnal flow variations were the range of flow conditions included in these evaluation studies. During the study period, composite primary effluent BOD_5 concentrations ranging from below 100 mg/L up to 380 mg/L showed no adverse effects on activated sludge phosphorus removal.

Other Factors

The trickling filter performance observed at the Back River Wastewater Treatment Plant consistently showed significantly lower levels of phosphorus removal than the activated sludge system. The recycle of all sludge handling liquors in the Baltimore system contributed to the high phosphorus load on secondary treatment and may have influenced this low trickling filter phosphorus removal. However, it is difficult to envision that the trickling filter could remove amounts of phosphorus in a manner comparable to the activated sludge system.

The precise mechanism whereby phosphorus removal takes place at Baltimore has not been defined, and the full-scale data observed in this study were not adequate for solution of this question. The observed release of phosphorus over that of the incoming primary effluent and return sludge (at the inlet end of the aeration tank) and the maximum pH value as low as 6.7 do not appear to be compatible with the calcium precipitation explanation of phosphorus removal. Also, release and uptake of magnesium ion, which appears to parallel that of phosphate across the activated sludge system, is not explained by current precipitation explanations. It should be noted that Baltimore's domestic wastewater cannot be considered as a hard wastewater, and the metal ion concentrations do not appear to be abnormally high.

Some additional observations appear to suggest biological sludge as the mechanism of phosphorus removal at Baltimore. One explanation is the apparent sensitivity of phosphorus removal to upset by abrupt solids wasting and mixing configuration; since it required as much as 3 to 4 days to recover once the removal ability was seriously impaired. Another is the rapid release of phosphorus when oxygen-limiting conditions occur in the aeration tank and recovery upon adequate aeration, without significant changes in pH taking place.

A further indication of solids dependency is the movement of the point in the system of most rapid reduction in phosphorus concentration. This reduction was observed to vary anywhere from the one-quarter point to the end of the aeration tank, and did not necessarily correspond to a sharp change in D.O. or pH. Biological solids involvement was also indicated by laboratory studies, which showed a significant release of phosphorus on long-term aeration at high levels of pH.

Optimization

The following general observations indicate that normal operating conditions at the activated sludge system of the Back River Wastewater Treatment Plant were close to the optimum for phosphorus removal for this particular plant:

1. Changes from plug flow (in the form of other mixing configurations) impaired the phosphorus removal.

2. A higher degree of aeration, beyond the 3-5 mg/L D.O. at the end of the aeration tank, at Baltimore (necessary for keeping oxygen from being limiting parameter), appeared to offer no improvement in phosphorus removal.

3. Suspended solids levels above 2,000 mg/L did not provide any improvement in phosphorus removal.

4. Continuous sludge wasting, with the maximum rate of wasting rarely exceeding 3 times the overall average rate for any extended period of time, appeared necessary to eliminate any phosphorus removal impairment stimulated by abrupt wasting of suspended solids.

5. A wide range of hydraulic loadings showed no negative effect on phosphorus removal; thus, hydraulic loading, within the range encountered in this study, (aeration detention times of 2.5 to 12 hours) is not a significant factor in optimization of activated sludge phosphorus removal at Baltimore.

One very necessary factor to the optimization of activated sludge phosphorus removal is the provision somewhere in the treatment system of a positive phosphorus removal and disposal stage for the sludge-handling supernatant wastewaters. The most economical alternative for terminal phosphorus removal will very likely be different for each treatment plant.

An assessment of the application of the type of activated sludge phosphorus removal observed at Baltimore to other municipal wastewaters is beyond the scope of this research study. However, no obvious unique wastewater characteristics or abnormal metal ion concentrations that may limit the application of this process were observed at Baltimore during the field study portion of this project. At the present level of understanding of the phenomenon, only actual experimentation at a particular location could truly confirm the applicability of this form of activated sludge phosphorus removal. Observations at other activated sludge plants across the United States further encourage the possibility of wide application.

SECTION V

ACKNOWLEDGEMENTS

The support of the City of Baltimore, and particularly the Bureau of Engineering of the Department of Public Works, is acknowledged with sincere thanks. Mr. William A. Hasfurther, Chief, Division of Wastewater, provided valuable assistance.

The plant modification, laboratory and analytical installation and project maintenance support were provided by the supervisory and maintenance staff of the Back River Wastewater Treatment Plant operating staff, and particular recognition is given to Mr. C. H. Hawthrone, Superintendant, and Mr. R. Harmon, Mr. K. Hartman, Mr. C. Achatz, and Mr. H. Urtes.

Activated sludge treatment plant operating staff made a significant contribution to the completion of the field portion of this project and particular acknowledgement is made of the efforts of D. McCauley, S. Nierwienski, L. Caldarone, R. Gernhart, W. Byard, and J. Bradshaw.

The field studies, analytical work, data analysis and interpretation and report preparation were performed by ROY F. WESTON, West Chester, Pennsylvania. The field team consisted of Dr. W. F. Milbury, Project Scientist/Engineer, F. L. Doll, Project Chemist, P. J. Norenbrock, Laboratory Technician, and R. L. Wooten, Laboratory Technician. Mr. V. T. Stack, and Dr. M. N. Bhatla, contributed valuable guidance to this project.

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SECTION VI

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SECTION VII

LIST OF PUBLICATIONS PRODUCED AS A RESULT OF THIS STUDY

1. Milbury, W. F., Doll, F. L., Stack, V. T., Zaleiko, N. S., "A Comprehensive Instrumentation System for Simultaneous Monitoring of Multiple Chemical Parameters in a Municipal Activated Sludge Plant," presented at the Instrumentation Society of America Conference, Pittsburgh, Pennsylvania, (May 26, 1970).

2. Milbury, W. F., Stack, V. T., Bhatla, M. N., "Effect of Dissolved Oxygen on Phosphorus Removal in Municipal Activated Sludge Treatment," presented at 3rd Joint Meeting of the American Institute of Chemical Engineers and Instituto Mexicano De Ingenieros Quimicos, Denver, Colorado, September 2, 1970.

3. Milbury, W. F., McCauley, D., Hawthorne, C. H., "Operation of Conventional Activated Sludge for Maximum Phosphorus Removal," presented at the 43rd Annual Meeting, Water Pollution Control Federation, Boston, Massachusettes, October 6, 1970.

4. Milbury, W. F., Doll, F. L., Stack, V. T., "Simultaneous Determination of Total Phosphorus and Total Kjeldahl Nitrogen in Activated Sludge with the Technicon Continuous Digester System", presented at 1970 Technicon International Congress, New York Hilton Hotel, New York, November 3, 1970.

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Table A-1

Baltimore Phosphate Removal Study

Activated Sludge Plant Flowmeter Calibration Tests
Lithium Salt Dilution Tests

	Lithium Salt Dilution Tests					Actual Meter Readings		
	Tracer Feed							
Process Flow	Concentration mg/L	Addition Rate gpm	Downstream Tracer Concentration mg/L	Computed Rate gpm	Computed Rate mgd	Chart Reading mgd	Meter Totalizer mgd	Meter Location
No. 1 Return Sludge	39,000	0.108	3.68	1,140	1.64	1.65 1.60	1.70 1.72	Inlet Outlet
No. 2 Return Sludge	39,400	0.104	3.60	1,140	1.64	1.58 1.60	1.45 1.51	Inlet Outlet
No. 1 Primary Effluent	41,200	0.220	2.88	3,140	4.53	4.55	3.93	Inlet
No. 2 Primary Effluent	39,200	0.201	2.36	3,330	4.79	4.40	3.80	Inlet
Total Secondary Effluent	81,000	0.228	1.60	11,500	16.6	16.5 21.0	---- 19.8	Inlet[1] Outlet[2]

[1] Obtained by adding two primary effluent feed rates and subtracting the wasting rate.

[2] Observed at Bethlehem Steel secondary effluent reuse flowmeter.

Note: These tests were done on 5/28/69 and 6/3/69. All meters were of the Venturi type.

Table A-2

BALTIMORE PHOSPHATE REMOVAL STUDY
Summary of Daily Analyses

							Date - 1969								
	6/24	6/25	6/26	6/27	6/30	7/1	7/2	7/3	7/7	7/8	7/9	7/10	7/11	7/14	7/15
Flow (MGD)															
SE-1	8.5	8.0	7.3	8.0	8.8	8.7	8.6	8.6	8.0	8.0	8.0	8.8	8.7	10.1	8.6
SE-2	8.7	8.7	8.7	8.7	8.9	8.8	8.8	8.8	8.6	8.5	8.9	8.9	9.0	9.5	7.8
RS-1	1.7	1.8	1.8	1.8	1.9	1.9	1.8	1.8	1.9	1.8	1.8	1.8	1.8	2.0	2.0
RS-2	1.8	1.8	1.8	1.8	1.9	2.0	2.0	1.9	1.9	1.9	1.9	1.8	1.8	1.9	2.0
X's-1	.11	.18	.18	0.1	0.1	0.18	0.12	0.08	0.07	.07	0.06	0.07	0.10	0.07	0.06
X's-2	.10	.18	.18	0.1	0.1	0.09	0.09	0.14	0.08	.07	0.05	0.11	0.11	0.07	0.06
TOT.P. (mg/L)															
PE	9.0	-	-	-	-	-	11.0	-	13.0	15.0	15.0	13.0	-	12.0	12.0
AT-1	54.0	-	-	-	-	89	85	-	82	61	70	63.	-	93	74
AT-2	50.0	-	-	-	-	105	76	-	77	70	73	52.	-	84	54
RS-1	115.0	-	-	-	-	>200	>200	-	>200	>200	>200	>200	-	300	250
RS-2	85.0	-	-	-	-	>200	>200	-	>200	>200	>200	>200	-	274	240
SE-1	2.0	-	-	-	-	-	6.0	-	4.0	13.0	6.0	10.0	-	<1.0	16.0
SE-2	1.0	-	-	-	-	-	13.0	-	3.0	15.0	9.0	8.0	-	6.0	18.0
TOT.KN (mg/L)															
PE	13.0	-	-	-	-	-	27.0	-	30.0	28.0	25.0	28.0	-	30.0	25.0
AT-1	73.0	-	-	-	-	100	110	-	122	126	124	122	-	126	130.
AT-2	69.0	-	-	-	-	130	120	-	128	114	124	128	-	136	134.
RS-1	122.0	-	-	-	-	>200	>200	-	>200	>200	>200	>200	-	220	210.
RS-2	110.0	-	-	-	-	>200	>200	-	>200	>210	>200	>200	-	220	210.
SE-1	9.0	-	-	-	-	-	13.0	-	22.0	20.0	12.0	18.0	-	22.0	18.
SE-2	9.0		-	-	-	-	15.0	-	18.0	18.0	13.0	22.0	-	20.0	19.
SS (mg/L)															
PE	128	116	119	133	206	149	132	128	121	107	114	92	118	133	85
AT-1	2300	2295	2260	2185	2090	2125	2170	2260	2080	2105	2220	2500	2500	1980	2130
AT-2	2250	2105	2240	2205	2070	2080	2160	2210	2030	2060	2100	2290	2310	1920	2160
RS-1	11100	-	-	-	8650	10140	8620	-	9480	9980	10540	10700	-	11400	10250
RS-2		-	-	-	7520	8520	8540	-	9100	9950	11320	11120	-	10920	10820
SE-1	10	2	9	5	-	6	10	10	2	19	25	15	13	17	25
SE-2	13	5	11	10	6	7	11	19	11	22	30	28	18	11	26
PERCENT VSS (VSS/SS)															
PE	-	-	-	-	66	51	61	-	68	84	67	77	-	-	59
AT-1	73	72	-	-	73	73	74	-	74	74	74	75	-	74	73
AT-2	73	73	-	-	74	74	75	-	73	78	75	77	-	76	78
SVI															
AT-1	103	114	105	102	101	100	101	100	89	112	125	114	119	85	105
AT-2	100	102	107	105	109	112	119	117	105	123	139	157	148	86	107
TEMP. °F.															
PE	67	67	66	69	68	67	69	69	68	69	68	68	69	69	70
SE-1	67	67	66	70	68	68	70	69	68	69	69	70	70	69	70
SE-2	67	67	66	70	68	68	70	69	68	69	69	70	70	69	70
BOD_5 (mg/L)															
PE	-	165	250	-	-	240	300	-	220	220	215	220	-	190	210
SE-1	-	9	34	-	-	23	19	-	24	32	20	24	-	18	23
SE-2	-	7	38	-	-	26	32	-	24	36	33	32	-	21	34
TOC (mg/L)															
PE	-	-	-	-	-	-	120	100	115	100	85	-	-	-	245
SE-1	-	-	-	-	-	-	20	25	25	25	20	-	-	-	115
SE-2	-	-	-	-	-	-	30	35	25	30	30	-	-	-	130

Table A-2
(continued)

BALTIMORE PHOSPHATE REMOVAL STUDY
Summary of Daily Analyses

Date - 1969

	7/16	7/17	7/18	7/21	7/22	7/23	7/24	7/25	7/29	7/30	7/31	8/4	8/5	8/6	8/7
Flow (MGD)															
SE-1	9.0	8.0	8.8	8.9	8.8	8.8	9.0	9.0	8.0	8.7	8.6	8.1	7.9	7.4	7.0
SE-2	9.3	9.0	9.0	9.1	9.0	9.1	9.0	9.0	9.0	9.2	9.2	7.2	6.7	6.4	5.5
RS-1	2.0	2.0	2.0	2.2	2.2	2.2	2.1	2.1	2.4	2.4	2.4	2.2	2.2	2.2	2.0
RS-2	1.8	2.0	2.1	2.2	2.2	2.2	2.1	2.1	2.2	2.2	2.2	2.2	2.2	1.6	1.6
X' s-1	0.11	0.15	0.18	0.15	0.16	0.16	0.12	0.10	.13	.15	.16	.14	.13	.12	.13
X' s-2	0.10	0.15	0.19	0.09	0.11	0.10	0.11	0.11	.16	.17	.17	.23	.21	.22	.22
TOT.P. (mg/L)															
PE	14.0	13.0	-	-	11.0	10.0	14.0	-	13.0	10.5	11.0	8.0	9.0	10.0	10.0
AT-1	76	66	-	-	78	70	73	-	106	105	98	92	92	96	80
AT-2	48	39	-	-	54	56	48	-	78	74	78	62	65	67	58
RS-1	153	220	-	-	278	260	245	-	238	274	280	-	236	226	310
RS-2	140	180	-	-	184	158	162	-	216	246	240	-	240	200	260
SE-1	11.0	8.0	-	-	5.0	<1.0	<1.0	-	-	4.0	12.0	<1.0	1.0	2.0	6.0
SE-2	12.0	10.0	-	-	12.0	8.0	8.0	-	-	7.0	18.0	2.0	2.0	2.0	4.0
TOT.KN (mg/L)															
PE	38.0	32.0	-	-	22.0	28.0	27.0	-	29.0	30.0	[illegible]	28.0	25.0	28.0	25.0
AT-1	150	148	-	-	120	119	125	-	145	138	[illegible]	148	145	121	145
AT-2	152	130	-	-	135	151	114	-	141	122	126	107	108	75	61
RS-1	210	210	-	-	220	218	215	-	>200	274	>200	-	308	220	410
RS-2	204	210	-	-	218	216	214	-	>200	246	>200	-	332	216	380
SE-1	22.0	22.0	-	-	17.0	14.0	16.0	-	18.0	18.0	18.0	14.0	16.0	15.0	13.0
SE-2	24.0	20.0	-	-	22.0	18.0	21.0	-	18.0	18.0	18.0	15.0	17.0	14.0	13.0
SS (mg/L)															
PE	133	122	127	97	99	94	115	104	101	114	114	127	136	110	106
AT-1	2370	2450	2330	1850	2130	2090	2050	2040	2130	2220	2110	2150	2140	2090	2150
AT-2	2230	2220	2048	1940	2070	1940	1940	1930	1650	1660	1665	1580	1530	1400	1360
RS-1	10630	10120	-	-	9420	13660	7550	-	9830	9411	9160	-	6753	9504	-
RS-2	10950	9760	-	-	9630	8950	8510	-	8710	8192	9030	-	7493	7732	-
SE-1	12	49	29	23	15	18	25	23	9	3	20	5	7	7	20
SE-2	14	19	34	25	7	17	25	24	13	4	19	15	14	10	15
PERCENT VSS (VSS/SS)															
PE	-	-	-	-	38	-	62	-	-	-	76	-	-	-	-
AT-1	77	78	-	-	77	75	75	-	76	71	77	75	76	74	-
AT-2	82	80	-	-	80	79	78	-	73	76	79	76	79	82	-
SVI															
AT-1	112	115	107	82	87	82	50	87	49	90	95	92	97	103	106
AT-2	108	97	99	87	96	87	53	68	58	76	76	52	51	55	51
TEMP. °F.															
PE	70	70	70	69	69	69	68	-	69	70	71	-	-	-	-
SE-1	71	71	72	71	70	70	69	-	69	71	71	-	-	-	-
SE-2	71	71	72	71	70	70	69	-	69	71	71	-	-	-	-
BOD_5 (mg/L)															
PE	216	183	-	-	105	159	150	-	96	204	230	138	160	150	165
SE-1	27	31	-	-	36	19	20	-	4	12	16	5	9	10	13
SE-2	35	32	-	-	36	26	54	-	5	21	20	15	16	7	12
TOC (mg/L)															
PE	285	265	250	285	155	-	205	255	165	270	245	95	130	145	120
SE-1	120	130	110	120	105	125	90	100	70	105	90	20	35	35	35
SE-2	135	135	135	120	120	145	120	125	80	110	105	30	35	35	35

Table A-2
(continued)

BALTIMORE PHOSPHATE REMOVAL STUDY
Summary of Daily Analyses

	Date - 1969														
	8/8	8/11	8/12	8/13	8/14	8/15	8/18	8/19	8/20	8/21	8/22	8/25	8/26	8/27	8/28
FLOW (MGD)															
SE-1	7.4	8.4	8.2	8.2	8.1	8.0	7.7	7.8	6.1	8.1	8.1	8.5	8.3	8.0	6.3
SE-2	5.6	6.7	6.3	6.5	6.5	6.6	7.1	6.7	4.1	6.9	7.1	9.3	9.5	9.1	6.4
RS-1	2.0	2.2	2.1	1.6	1.3	1.5	2.0	2.0	2.2	1.8	1.8	2.0	1.9	1.8	1.8
RS-2	1.6	2.0	2.4	1.9	1.2	1.7	1.1	2.0	2.0	2.0	2.0	2.0	2.5	3.6	3.6
X's-1	.15	.09	0.08	.10	.07	-	.08	.10	.16	0.14	0.15	.19	.12	.08	.14
X's-2	.11	.05	0.21	.57	.33	-	.65	.08	.05	0.00	0.00	.05	.02	.02	.08
TOT.P. (mg/L)															
PE	-	7.0	9	11	11	-	9.5	9	6.8	145	-	8.0	7	7.5	6.6
AT-1	-	89	98	95	107	-	108	98	102	94	-	136	106	128	137
AT-2	-	87	92	74	96	-	78	48	52	72	-	140	138	160	162
RS-1	-	160	-	250	250	-	388	312	232	264	-	252	286	264	250
RS-2	-	154	-	200	168	-	216	164	160	204	-	260	292	286	272
SE-1	-	<1.0	<1.0	<1.0	<1.0	-	2.0	3.0	1.5	1.0	-	1.5	1.0	0.5	1.0
SE-2	-	<1.0	2.0	<1.0	7.0	-	3.0	4.5	2.0	1.5	-	2.0	1.5	1.5	1.5
TOT.KN (mg/L)															
PE	-	21	21	21	22.0	-	22	25	20.5	17.5	-	20	26	19.5	25
AT-1	-	149	163	155	174	-	125	106	117	107	-	128	104	98	120
AT-2	-	135	145	110	156	-	78	63	70	90	-	135	125	148	160
RS-1	-	245	242	260	300	-	454	400	304	344	-	250	270	280	258
RS-2	-	132	202	250	250	-	256	212	200	272	-	275	290	290	276
SE-1	-	15	13	13	13	-	17	17	16	13	-	13	10	14	9.5
SE-2	-	17	15	13	15	-	18.5	15.5	18	14.5	-	16	12.5	14	11.0
SS (mg/L)															
PE	143	133	117	121	126	143	123	133	113	149	126	139	167	130	144
AT-1	2240	2090	2175	2210	2010	2450	1980	2070	2085	2090	2140	1980	1940	2040	2540
AT-2	1405	1650	1740	1560	1830	1010	1020	910	1080	1530	1670	2550	2600	3110	3670
RS-1	-	9191	9474	12960	14850	-	9200	8880	7273	8335	-	9630	9511	9074	7316
RS-2	-	8315	6886	6540	4580	-	3970	3650	4399	6207	-	11022	11742	9517	8858
SE-1	11	11	11	3	26	15	5	18	11	6	10	1	6	12	2
SE-2	11	8	13	2	17	31	12	14	11	11	10	9	10	8	5
PERCENT VSS (VSS/SS)															
PE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT-1	-	73	72	77	76	-	65	72	70	71	-	70	71	71	68
AT-2	-	72	71	72	76	-	61	73	73	70	-	70	67	71	67
SVI															
AT-1	101	93	90	88	66	81	101	95	109	119	125	139	134	139	140
AT-2	54	61	72	77	86	79	115	125	115	133	153	191	229	254	257
TEMP. °F.															
PE	-	-	-	-	-	70	70	71	70	69	70	70	71	70	70
SE-1	-	-	-	-	-	72	71	71	70	70	70	70	71	70	71
SE-2	-	-	-	-	-	72	71	71	70	70	70	70	71	70	71
BOD$_5$ (mg/L)															
PE	-	138	170	190	185	-	130	155	100	60	-	180	190	195	-
SE-1	-	11	10	15	13	-	9	9	9	15	-	11	10	9	10
SE-2	-	8	7	8	10	-	8	8	7	11	-	20	17	9	13
TOC (mg/L)															
PE	125	90	110	120	110	-	70	80	85	100	-	85	180	145	155
SE-1	35	25	20	35	55	-	20	35	30	25	-	20	35	25	20
SE-2	35	20	25	35	50	-	30	25	35	35	-	20	45	35	30

Table A-2
(continued)

BALTIMORE PHOSPHATE REMOVAL STUDY
Summary of Daily Analyses

	Date - 1969														
	8/29	9/2	9/3	9/4	9/5	9/8	9/9	9/10	9/11	9/12	9/15	9/16	9/17	9/18	9/19
FLOW (MGD)															
SE-1	6.6	6.2	6.9	8.1	9.0	6.3	9.4	9.0	9.0	8.9	7.8	7.7	8.4	8.7	8.7
SE-2	5.2	6.5	7.1	6.3	4.0	6.1	4.3	4.4	4.5	4.3	9.0	8.7	9.5	11.7	11.7
RS-1	1.8	1.9	1.9	1.8	1.8	1.9	1.9	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.8
RS-2	3.6	2.3	3.0	3.4	3.8	1.6	1.6	1.6	1.6	1.3	2.7	2.9	2.0	2.0	2.5
X's-1	.20	.17	.23	.20	.22	.13	.17	.17	.17	0.22	.22	.15	.14	.24	.22
X's-2	.13	.08	.05	.15	.72	.19	.21	.21	.22	0.08	0.09	.29	.56	.31	.21
TOT.P. (mg/L)															
PE	-	10.4	9.0	7.5	-	13.2	13.8	14.6	11.5	-	13.2	12.4	10.5	11.2	-
AT-1	-	120	126	102	-	84	85	101	93	-	126	105	103	100	-
AT-2	-	134	144	146	-	100	96	98	97	-	110	106	90	81	-
RS-1	-	-	-	356	-	284	284	180	330	-	225	310	364	354	-
RS-2	-	328	-	360	-	296	264	200	296	-	205	328	296	340	-
SE-1	-	-	2.0	2.0	-	3.5	6.8	4.0	2.6	-	-	-	2.2	3	-
SE-2	-	2.0	1.4	2.5	-	2.0	2.4	2.0	1.0	-	-	3.0	2.0	2	-
TOT.KN (mg/L)															
PE	-	24.6	21.4	23	-	30	28	29	28.5	-	26	26.5	24.5	28.5	-
AT-1	-	152	130	136	-	155	165	170	164	-	170	160	165	160	-
AT-2	-	160	158	188	-	165	165	144	160	-	149	166	138	133	-
RS-1	-	-	260	440	-	456	460	240	480	-	380	460	480	488	-
RS-2	-	420	440	416	-	460	440	300	268	-	364	470	440	480	-
SE-1	-	5.6	6.0	6.4	-	13.0	19.0	15.5	10.2	-	-	15	8.4	15.2	-
SE-2	-	5.8	7.2	7.8	-	11.6	8.8	7.6	3.5	-	6.4	13.4	9.0	10.5	-
SS (mg/L)															
PE	156	168	198	191	161	147	187	164	182	183	171	160	196	203	202
AT-1	2770	2470	2230	2250	2150	2075	2180	2360	2310	2460	2110	2260	2230	2240	1440
AT-2	3620	2930	2790	3220	3230	2450	2360	2190	2120	2030	2010	2370	1850	1730	1990
RS-1	-	-	4279	9441	-	8009	10625	12050	10150	-	9390	9347	9514	9923	-
RS-2	-	8149	9401	8515	-	9158	8711	8348	7842	-	7150	9081	8475	9966	-
SE-1	2	15	5	12	3	5	6	6	2	10	-	10	2	14	12
SE-2	23	16	11	12	2	11	2	2	6	5	-	11	4	13	10
PERCENT VSS (VSS/SS)															
PE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT-1	-	68	66	62	-	67	68	72	71	-	74	71	69	70	-
AT-2	-	68	63	65	-	66	66	68	72	-	79	70	73	74	-
SVI															
AT-1	125	219	226	144	158	193	158	183	279	262	227	249	203	161	153
AT-2	211	255	290	279	271	232	191	195	159	179	339	369	290	181	358
TEMP. °F.															
PE	70	71	70	70	70	70	69	70	70	69	70	70	71	68	68
SE-1	71	71	70	70	70	70	69	70	70	68	71	70	71	70	68
SE-2	71	71	70	70	70	70	69	70	70	68	71	70	71	70	68
BOD_5 (mg/L)															
PE	-	140	-	-	-	173	192	380	180	-	360	297	157	165	-
SE-1	-	20	-	-	-	58	48	45	23	-	33	38	10	14	-
SE-2	-	25	-	-	-	27	32	35	30	-	21	26	9	10	-
TOC (mg/L)															
PE	165	95	105	95	105	65	85	85	-	-	-	-	125	110	100
SE-1	35	-	-	10	15	10	35	25	-	-	5	15	5	5	15
SE-2	40	-	15	20	10	5	10	10	-	-	10	20	10	20	30

Table A-2
(continued)

BALTIMORE PHOSPHATE REMOVAL STUDY
Summary of Daily Analyses

Date - 1969

	9/22	9/23	9/24	9/25	9/29	9/30	10/1	10/2	10/3	10/6	10/7	10/8	10/9	10/10	10/13
FLOW (MGD)															
SE-1	7.4	7.3	7.3	6.0	9.9	9.7	10.0	9.9	9.6	10.1	10.8	10.2	11.5	10.6	9.2
SE-2	6.0	6.2	6.3	6.3	6.0	6.0	6.2	6.0	5.2	6.0	5.7	6.0	5.5	7.5	9.0
RS-1	2.1	2.0	2.0	2.0	2.0	2.0	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
RS-2	2.2	2.1	2.2	2.2	2.0	2.0	2.0	1.9	1.9	2.0	2.0	2.0	2.0	2.0	2.0
X's-1	.06	.11	.24	.45	.08	.13	.19	.29	.23	.14	.15	.19	.18	.24	.14
X's-2	.66	.43	.10	.40	.09	.15	.13	.19	.24	.14	.14	.19	.14	.15	.05
TOT.P (mg/L)															
PE	11.5	9.8	9.8	-	12.8	13.0	-	-	-	-	10.8	9.8	-	-	-
AT-1	106	93	82	-	108	118	86	76	-	-	91	72	-	-	-
AT-2	98	68	78	-	100	106	98	90	-	-	104	86	-	-	-
RS-1	296	228	264	-	320	326	326	286	-	-	312	252	-	-	-
RS-2	236	152	196	-	273	320	320	266	-	-	268	220	-	-	-
SE-1	1.5	1.8	2.3	-	1.0		-	-	-	-	1.5	3.0	-	-	-
SE-2	1.0	1.0	1.0	-	0.5	1.5	-	-	-	-	2.4	1.5	-	-	-
TOT.KN (mg/L)															
PE	27.5	31	27	-	28.4	-	-	-	-	-	13	8.4	-	-	-
AT-1	114	101	106	-	116	150	124	133	-	-	81	70	-	-	-
AT-2	124	74	82	-	124	140	136	136	-	-	78	72	-	-	-
RS-1	360	240	320	-	420	453	480	480	-	-	328	268	-	-	-
RS-2	280	168	232	-	333	400	373	326	-	-	224	184	-	-	-
SE-1	14.6	16.0	15	-	17.5	-	-	-	-	-	5.4	8.2	-	-	-
SE-2	15.0	15.4	13.2	-	19.2	-	-	-	-	-	7.0	5.6	-	-	-
SS (mg/L)															
PE	179	173	161	155	165	205	178	209	168	136	148	158	178	160	141
AT-1	2000	2340	2340	2210	2005	2150	2170	2280	2290	1660	1805	1750	1970	2170	2030
AT-2	2250	1760	1750	1870	1680	1950	2060	2130	1970	1690	1760	1790	1850	1950	2010
RS-1	8059	9437	8971	-	7726	9561	9867	10906	-	-	8928	9550	-	-	-
RS-2	6630	5914	6274	-	6334	6986	7103	7676	-	-	6047	6314	-	-	-
SE-1	11	11	8	19	4	10	12	7	12	5	8	10	3	12	11
SE-2	9	10	6	9	6	6	11	5	6	5	4	9	7	10	9
PERCENT VSS (VSS/SS)															
PE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT-1	68	72	74	-	72	71	72	68	-	-	71	75	-	-	-
AT-2	70	74	71	-	72	72	72	69	-	-	74	69	-	-	-
SVI															
AT-1	159	188	279	253	153	209	222	244	286	146	174	207	228	210	172
AT-2	349	200	218	205	164	195	187	212	206	178	249	247	325	305	376
TEMP. °F.															
PE	67	67	67	67	67	68	67	67	68	66	66	66	66	65	66
SE-1	68	68	-	-	-	-	-	-	-	-	-	-	-	-	-
SE-2	68	68	68	68	67	68	68	68	68	65	65	66	66	66	66
BOD_5 (mg/L)															
PE	154	225	220	-	57	114	135	96	-	-	178	150	-	-	-
SE-1	20	22	37	-	16	19	19	26	-	-	36	19	-	-	-
SE-2	16	10	19	-	9	4	11	11	-	-	19	16	-	-	-
TOC (mg/L)															
PE	95	100	105	100	70	100	105	105	-	125	90	125	125	-	-
SE-1	15	20	20	25	10	20	20	25	-	35	10	10	15	-	-
SE-2	15	20	20	30	15	20	20	25	-	25	10	15	25	-	-

Table A-2
(continued)

BALTIMORE PHOSPHATE REMOVAL STUDY

Summary of Daily Analyses

	Date - 1969														
	10/14	10/15	10/16	10/17	10/20	10/21	10/22	10/23	10/24	10/27	10/28	10/29	10/30	10/31	11/3
FLOW (MGD)															
SE-1	9.1	9.0	8.6	8.6	8.3	8.5	9.4	9.4	9.0	9.7	9.5	9.1	9.2	8.0	10.4
SE-2	9.0	9.3	9.6	9.5	9.5	8.0	9.8	8.4	7.1	9.5	9.5	9.5	9.5	9.5	4.1
RS-1	2.0	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
RS-2	1.5	1.1	1.3	1.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
X's-1	.16	.17	.23	.19	.09	.18	.20	.19	.18	.16	.11	.17	.27	.15	.14
X's-2	.11	.17	.10	.12	.09	.27	.19	.17	.16	.17	.10	.08	.25	.26	.14
TOT.P. (mg/L)															
PE	10.5	10.4	9.5	10	13.2	11.9	12.0	10.4	12.0	12.8	16.0	13.4	13.5	-	8.2
AT-1	108	104	122	122	79	64	59	59	-	-	117	101	83	-	106
AT-2	102	88	96	125	80	73	58	42	-	-	82	61	51	-	102
RS-1	256	248	250	288	250	-	182	235	-	-	375	291	460	-	310
RS-2	258	260	256	296	280	256	146	184	-	-	310	264	288	-	300
SE-1	1.2	0.5	.5	1.2	2.0	19.5	2.4	2.2	-	-	-	1.4	-	-	0.8
SE-2	2.8	1.2	.8	1.0	0.8	3.6	25.0	9.8	-	-	-	16.0	-	-	1.2
TOT.KN (mg/L)															
PE	34	40.0	32	24	38	36	29.4	43	-	-	-	-	-	-	22.4
AT-1	125	130	145	152	133	128	128	130	-	-	132	138	56	-	155
AT-2	122	116	125	150	124	122	143	122	-	-	120	114	52	-	132
RS-1	400	390	390	360	210	190	200	234	-	-	460	420	390	-	340
RS-2	400	410	415	420	228	220	188	220	-	-	460	426	249	-	350
SE-1	16.8	18.2	19.4	17.0	21.2	25	18.2	24.4	-	-	-	-	-	-	20
SE-2	17.0	17.8	16.6	12.6	20.8	25	27.0	29.3	-	-	-	-	-	-	20.8
SS (mg/L)															
PE	146	201	136	148	154	168	154	172	165	135	150	156	158	123	139
AT-1	2030	2300	2330	2270	1650	1750	1850	1895	2010	1770	1870	2040	2000	2150	1870
AT-2	2010	1980	1980	2170	1690	1810	1960	1870	1905	1890	1720	1990	2095	1898	1955
RS-1	9814	10743	10809	9707	7213	-	-	-	-	8392	8392	-	-	-	9657
RS-2	10746	13144	9284	11998	7509	-	-	-	-	6936	6936	-	-	-	6950
SE-1	21	12	16	11	-	18	10	16	19	6	18	9	14	11	10
SE-2	24	12	20	6	-	5	2	28	19	16	25	17	26	21	23
PERCENT VSS (VSS/SS)															
PE	62	62	59	56	80	-	-	-	-	46	75	-	-	-	76
AT-1	73	71	71	69	76	-	-	-	-	78	77	-	-	-	74
AT-2	76	72	72	71	77	-	-	-	-	76	76	-	-	-	72
SVI															
AT-1	-	194	200	153	114	117	103	94	99	97	97	96	102	105	107
AT-2	-	228	217	168	107	103	111	119	113	91	109	106	105	101	84
TEMP. °F.															
PE	67	65	65	65	66	66	63	61	61	61	60	60	60	60	62
SE-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SE-2	67	65	66	64	64	65	63	62	62	61	60	59	61	60	62
BOD$_5$ (mg/L)															
PE	156	189	171	195	96	120	105	150	-	148	159	-	211	229	132
SE-1	-	6	3	2	6	22	11	9	-	5	5	-	12	10	5
SE-2	6	9	5	7	4	15	28	38	-	11	15	-	25	25	9
TOC (mg/L)															
PE	155	155	145	130	-	105	100	95	110	140	155	145	120	130	154
SE-1	30	35	35	30	15	20	25	25	30	35	35	40	35	30	24
SE-2	30	35	35	20	10	20	30	45	25	35	40	40	40	40	23

Table A-2
(continued)
BALTIMORE PHOSPHATE REMOVAL STUDY
Summary of Daily Analyses

	Date - 1969														
	11/4	11/5	11/6	11/7	11/10	11/11	11/12	11/13	11/14	11/15	11/16	11/17	11/18	11/19	11/20
FLOW (MGD)															
SE-1	10.8	10.5	10.6	10.3	8.0	8.2	8.4	8.6	8.1	8.0	8.3	8.3	8.8	3.0#	3.0#
SE-2	4.0	4.5	4.5	4.5	9.5	8.5	8.3	8.6	9.3	8.4	8.5	9.5	8.7	3.0#	3.0#
RS-1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.9
RS-2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
X's-1	.16	.24	.23	.22	.47	.20	.14	.15	.16	.15	.15	.49	.18	-	-
X's-2	.17	.14	.12	.17	.30	.18	.16	.17	.17	.15	.15	.26	.16	-	-
TOT.P. (mg/L)															
PE	13.5	13.2	11	8.6	11.2	13.0	10.4	-	12.5	-	-	11.6	10.0	-	-
AT-1	120	120	110	104	-	-	-	-	96	-	-	116	110	-	-
AT-2	118	116	114	120	-	-	-	-	61	-	-	104	86	-	-
RS-1	320	315	276	295	-	-	-	-	226	-	-	250	>225	-	-
RS-2	320	280	270	280	-	-	-	-	190	-	-	218	>225	-	-
SE-1	1.0	0.5	-	0.4	0.5	0.5	0.6	-	0.5	-	-	0.8	2.8	-	-
SE 2	0.5	0.5	-	0.4	0.5	0.8	5.2	-	10.4	-	-	2.8	-	-	-
TOT.KN (mg/L)															
PE	21	29.6	20.2	-	19.4	26.8	22.4	-	29.6	-	-	33.0	34.0	-	-
AT-1	146	146	110	144	-	-	-	-	112	-	-	152	144	-	-
AT-2	154	142	114	148	-	-	-	-	102	-	-	162	134	-	-
RS-1	350	320	276	320	-	-	-	-	260	-	-	350	330	-	-
RS-2	286	280	270	280	-	-	-	-	246	-	-	360	290	-	-
SE-1	17.6	14.4	-	-	18.0	16.4	15.0	-	25.6	-	-	21.0	19.2	-	-
SE-2	22.8	19.6	-	-	17.2	16.3	16.8	-	20.0	-	-	24.0	21.2	-	-
SS (mg/L)															
PE	134	127	156	156	140	134	131	211	151	140	107	145	136	106	140
AT-1	1980	1920	1970	1970	1770	1730	1875	2040	2180	2180	2040	1845	1900	1600	2024
AT-2	1960	2180	1870	1965	1850	1850	1825	1910	1940	1900	1940	1920	1910	2060	2090
RS-1	-	-	-	-	8125	-	-	-	-	-	-	-	8628	-	-
RS-2	-	-	-	-	7652	-	-	-	-	-	-	-	8368	-	-
SE-1	20	11	10	6	2	7	7	11	8	13	17	12	3	-	-
SE-2	15	15	17	6	8	5	11	14	6	10	17	10	10	-	-
PERCENT VSS (VSS/SS)															
PE	-	-	-	-	80	-	-	-	-	-	-	-	64	-	-
AT-1	-	-	-	-	72	-	-	-	-	-	-	-	79	-	-
AT-2	-	-	-	-	74	-	-	-	-	-	-	-	76	-	-
SVI															
AT-1	108	125	124	135	129	130	130	126	120	115	120	112	113	116	89
AT-2	82	90	109	123	129	139	146	141	138	139	132	139	138	131	115
TEMP.															
PE	61	60	59	59	62	58	59	59	58	56	59	58	58	60	56
SE-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SE-2	59	60	58	59	61	58	59	59	58	55	57	57	57	59	56
BOD$_5$ (mg/L)															
PE	136	171	161	205	186	180	215	-	150	-	-	-	197	-	-
SE-1	8	7	11	7	9	10	5	-	-	-	-	-	15	-	-
SE-2	5	6	6	5	7	9	8	-	18	-	-	-	14	-	-
TOC (mg/L)															
PE	130	125	120	-	-	145	130	180	135	175	140	145	160	-	-
SE-1	50	30	25	-	-	40	35	40	45	50	40	30	35	-	-
SE-2	35	35	30	-	-	40	40	45	45	60	40	35	45	-	-

# Systems down 15 hours per day

Table A-2
(continued)

BALTIMORE PHOSPHATE REMOVAL STUDY

Summary of Daily Analyses

Date - 1969

	11/23	11/24	11/25	11/26	11/27	11/28	11/29	11/30	12/1	12/2	12/3	12/4	12/5*	12/6	12/7
FLOW (MGD)															
SE-1	-	9.6	5.8	4.8	8.7	8.5	8.5	8.3	9.8	8.7	9.7	8.6	8.0	0.0	0.0
SE-2	-	9.8	7.2	4.4	9.0	9.0	9.0	8.8	9.8	8.4	9.7	9.7	9.0	14.8	20.2
RS-1	-	1.8	2.0	2.0	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	0.0	0.0
RS-2	-	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	4.4	4.4
X's-1	-	.27	.13	.11	.15	.33	.14	.20	.26	.14	.31	.26	.35	0.0	0.0
X's-2	-	.00	.00	.00	0.0	.00	.08	.15	.24	.12	.19	.23	.20	.50	.30
TOT.P. (mg/L)															
PE	-	13.6	16.2	-	-	13.4	-	-	9.4	14.6	9.4	9.8	-	10.2	8.2
AT-1	-	138	145	132	-	114	-	-	108	132	99	114	-	0	0
AT-2	-	78	80	102	-	96	-	-	96	109	98	107	-	126	102
RS-1	-	-	664	612	-	388	-	-	472	484	520	520	-	0	0
RS-2	-	408	360	168	-	324	-	-	440	488	480	456	-	560	592
SE-1	-	1.0	2.6	-	-	0.4	-	-	2.4	1.8	1.4	1.2	-	0	0
SE-2	-	3.0	5.2	-	-	0.2	-	-	2.8	1.2	1.0	1.4	-	.8	1.6
TOT.KN (mg/L)															
PE	-	40.0	32.0	-	-	36.0	-	-	35.0	40.0	36.0	40.0	-	29.2	28.8
AT-1	-	132	134	136	-	162	-	-	149	188	154	162	-	0	0
AT-2	-	92	94	106	-	156	-	-	143	163	152	159	-	186	148
RS-1	-	648	600	544	-	520	-	-	484	500	516	504	-	0	0
RS-2	-	424	400	192	-	496	-	-	472	516	500	492	-	532	530
SE-1	-	16.4	19.0	-	-	19.4	-	-	16.5	14.8	15.0	14.6	-	0	0
SE-2	-	15.8	17.8	-	-	19.2	-	-	17.4	14.2	15.0	15.6	-	17.2	16.2
SS (mg/L)															
PE	143	135	145	136	117	137	115	101	113	177	157	135	126	110	86
AT-1	2350	2254	2435	2025	2155	2075	2025	1990	1890	2130	1940	1930	1805	0	0
AT-2	1650	1270	1450	1280	1475	1760	2010	1955	1755	2010	1890	2005	2180	2147	1913
RS-1	-	-	-	-	-	10606	-	-	-	-	-	-	-	-	-
RS-2	-	-	-	-	-	6327	-	-	-	-	-	-	-	-	-
SE-1	15	15	20	14	13	11	1	4	13	19	13	25	10	0	0
SE-2	16	15	10	13	16	15	3	6	15	16	10	22	12	7	9
PERCENT VSS (VSS/SS)															
PE	-	-	-	-	-	42	-	-	-	-	-	-	-	-	-
AT-1	-	-	-	-	-	67	-	-	-	-	-	-	-	-	-
AT-2	-	-	-	-	-	76	-	-	-	-	-	-	-	-	-
SVI															
AT-1	120	124	123	142	131	132	111	136	134	151	152	152	144	0	0
AT-2	105	120	112	123	123	128	133	135	139	147	157	150	153	180	178
TEMP. °F.															
PE	55	56	55	58	54	54	55	54	56	55	54	54	53	55	54
SE-1	-	-	55	-	-	-	-	-	-	-	-	-	-	0	0
SE-2	56	54	56	56	54	54	54	53	54	54	54	53	53	53	53
BOD_5 (mg/L)															
PE	-	114	220	-	-	130	-	-	140	210	168	195	-	-	-
SE-1	-	5	7	-	-	7	-	-	6	13	10	11	-	-	-
SE-2	-	4	6	-	-	9	-	-	6	8	7	9		-	-
TOC (mg/L)															
PE	-	120	106	125	160	120	127	110	67	175	130	-	-	148	131
SE-1	-	30	16	45	45	35	29	30	24	45	45	-	-	0	0
SE-2	-	25	20	35	40	35	34	30	23	45	45	-	-	50	44

*System No. 1 out of operation from 12/5/69 to 12/22/69

Table A-2
(continued)

BALTIMORE PHOSPHATE REMOVAL STUDY
Summary of Daily Analyses

	Date - 1969														
	12/8	12/9	12/10	12/11	12/12	12/13	12/14	12/15	12/16	12/17	12/18	12/19	12/20	12/21	12/22
FLOW (MGD)															
SE-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE-2	20.2	20.6	19.4	17.0	16.8	16.6	16.7	16.9	12.5	8.3	7.5	7.6	7.9	7.9	7.9
RS-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RS-2	4.4	4.3	4.3	4.2	4.1	4.0	4.2	4.2	4.2	3.4	3.4	4.4	4.7	4.6	4.8
X's-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
X's-2	.27	.28	.36	.32	.35	.33	.23	.22	.36	.51	.52	.42	.08	.06	.06
TOT. P. (mg/L)															
PE	9.2	-	13.6	8.6	-	-	11.0	10.6	9.8	11.0	8.8	13.0	10.6	15.6	10.2
AT-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AT-2	122	142	144	154	130	-	128	126	128	138	106	81	84	90	-
RS-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RS-2	>300	296	726	470	-	-	504	510	448	>325	232	101	115	128	-
SE-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE-2	0.5	-	1.3	1.1	1.4	-	2.8	4.6	5.4	0.4	2.6	11.6	7.2	6.0	9.4
TOT.KN (mg/L)															
PE	35.0	-	26.1	26.0	-	-	22.0	28.0	25.0	25.0	22.8	27.0	27.0	25.0	23.8
AT-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AT-2	158	140	198	220	204	-	204	202	199	204	186	106	112	119	-
RS-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RS-2	>300	>300	>600	480	-	-	490	460	456	428	376	126	144	160	-
SE-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE-2	13.8	-	15.8	12.8	16.2	-	22.0	17.6	22.0	18.0	16.4	23.2	20.0	20.8	21.0
SS (mg/L)															
PE	98	101	123	118	102	98	109	105	106	83	88	88	86	89	130
AT-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AT-2	2070	2240	2420	2370	2190	2100	2045	2140	2353	2590	1830	1410	1482	1750	1965
RS-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RS-2	8560	-	10670	-	-	-	-	-	9727	-	-	-	-	-	4280
SE-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE-2	6	12	12	14	12	21	15	12	13	6	5	-	-	-	-
PERCENT VSS (VSS/SS)															
PE	22	-	79	-	-	-	-	-	67	-	-	-	-	-	78
AT-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AT-2	76	-	77	-	-	-	-	-	74	-	-	-	-	-	76
SVI															
AT-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AT-2	155	185	187	182	108	158	160	144	158	209	148	156	153	147	171
TEMP. °F.															
PE	54	54	54	53	53	53	53	53	51	51	52	51	51	52	50
SE-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE-2	52	52	52	53	53	51	51	51	51	51	52	51	51	50	49
BOD$_5$ (mg/L)															
PE	135	168	177	230	177	-	130	110	165	186	200	-	-	-	-
SE-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE-2	23	16	28	11	13	-	10	9	14	8	7	-		-	-
TOC (mg/L)															
PE	144	111	109	106	146	133	108	102	111	118	112	115	87	98	79
SE-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SE-2	33	26	22	30	34	29	22	19	23	33	19	24	19	28	21

Table A-2
(continued)

BALTIMORE PHOSPHATE REMOVAL STUDY
Summary of Daily Analyses

	Date - 1969 and 1970					
	12/23	2/12/70	2/13/70	2/27/70	2/28/70	3/1/70
FLOW (MGD)						
SE-1	5.7	8.5	8.5	8.0	8.5	8.5
SE-2	6.0	9.0	9.0	8.5	8.5	9.0
RS-1	2.0	2.0	2.0	2.0	2.0	2.0
RS-2	2.0	2.0	2.0	2.0	2.0	2.0
X's-1	0.1	-	-	-	-	-
X's-2	0.1	-	-	-	-	-
TOT.P. (mg/L)						
PE	-	13.8	7.0	16.5	18.0	10.2
AT-1	-	-	-	105	88	-
AT-2	-	-	-	-	-	-
RS-1	-	-	-	-	340	-
RS-2	-	-	-	-	-	-
SE-1	-	6.6	2.1	.5	.5	1.7
SE-2	-	7.2	2.0	1.5	2.5	3.5
TOT.KN (mg/L)						
PE	-	30.0	22.0	33.0	320	25.5
AT-1	-	-	-	175	142	-
AT-2	-	-	-	-	-	-
RS-1	-	-	-	-	505	-
RS-2	-	-	-	-	-	-
SE-1	-	19.4	12.2	17.0	15.5	16.5
SE-2	-	20.5	12.7	17.5	16.0	17.0
SS (mg/L)						
PE	110	112	160	170	150	145
AT-1	1,520	2,015	2,050	2,200	1,890	1,880
AT-2	1,610	2,050	2,040	2,210	1,980	1,850
RS-1	-	-	-	-	-	-
RS-2	-	-	-	-	-	-
SE-1	-	-	-	-	-	-
SE-2	-	-	-	-	-	-
PERCENT VSS (VSS/SS)						
PE	-	-	-	-	-	-
AT-1	-	-	-	76	-	-
AT-2	-	-	-	-	-	-
SVI						
AT-1	184	120	108	126	120	118
AT-2	175	110	105	124	118	110
TEMP. °F.						
PE	48	-	-	-	-	-
SE-1	48	-	-	-	-	-
SE-2	48	-	-	-	-	-
BOD_5 (mg/L)						
PE	-	-	-	-	-	-
SE-1	-	-	-	-	-	-
SE-2	-	-	-	-	-	-
TOC (mg/L)						
PE	74	-	-	-	-	-
SE-1	15	-	-	-	-	-
SE-2	16	-	-	-	-	-

Table A-3

Weekly Composite Metal Results for Common Primary Effluent

Baltimore Phosphate Removal Study

Date	Calcium mg/L	Magnesium mg/L	Iron mg/L	Aluminum mg/L	Copper mg/L	Zinc mg/L
7/14-17/69	28.9	11.3	3.1	-	0.3	0.7
7/22-25/69	24.0	11.0	2.3	2.0	0.4	1.5
7/29-31/69	30.0	11.5	2.3	3.5	0.3	0.6
8/4-8/69	30.0	11.0	2.5	3.5	0.3	0.7
8/11-15/69	24.5	12.5	2.7	2.5	0.3	0.8
8/18-22/69	23.0	9.0	1.5	2.5	0.2	0.7
8/25-29/69	25.5	8.8	3.0	1.6	0.7	0.8
9/2-5/69	22.5	9.2	4.5	2.1	0.4	0.9
9/8-12/69	21.8	8.8	3.8	2.9	0.4	1.2
9/15-19/69	24.0	9.6	3.5	2.6	0.3	0.9
9/20-26/69	23.0	10.7	6.2	1.6	0.4	0.9
9/29-10/3/69	27.0	10.8	4.4	3.8	0.6	1.6
10/7-10/69	25.5	12.5	-	1.6	0.9	0.9
10/14-17/69	26.0	13.0	6.0	1.9	0.4	1.9
10/20-23/69	-	10.0	3.5	1.2	0.4	0.9
10/28-31/69	-	11.0	2.6	0.8	0.2	1.2
11/3-7/69	-	11.8	1.9	-	-	-
11/10-14/69	-	13.6	1.3	-	-	-
11/17-20/69	-	10.4	3.3	-	-	-
11/24-28/69	26.0	13.0	2.5	1.0	-	-
12/1-4/69	26.5	14.2	3.7	1.5	-	-
12/6-11/69	25.5	11.8	2.3	1.5	-	-
12/11-16/69	25.0	13.7	4.8	3.0	-	-
12/18-23/69	22.0	10.6	2.6	0.9	-	-
Average	25.3	11.2	3.2	2.1	0.4	1.0
Range	21.8-30.0	8.8-14.2	1.3-6.0	0.8-3.8	0.2-0.9	0.6-1.9

Table A-3
(continued)

Weekly Composite Metal Results for Control Final Effluent (System No. 1)

Baltimore Phosphate Removal Study

Date	Calcium mg/L	Magnesium mg/L	Iron mg/L	Aluminum mg/L	Copper mg/L	Zinc mg/L
7/14-17/69	23.3	8.4	0.5	<0.5	<0.1	0.2
7/22-25/69	28.0	10.7	0.9	-	0.2	0.4
7/28-31/69	22.0	10.0	0.9	1.5	0.2	0.2
8/4-8/69	28.0	10.0	0.8	1.0	0.1	0.2
8/11-15/69	-	7.2	0.8	-	<0.1	0.4
8/18-22/69	22.0	7.2	0.6	1.0	0.1	0.4
8/25-29/69	22.0	7.6	1.3	0.5	0.1	0.3
9/2-5/69	25.0	7.7	0.7	<0.5	<0.1	0.2
9/8-12/69	22.8	-	1.7	0.8	0.1	0.4
9/15-19/69	21.5	8.4	1.7	1.5	0.1	0.5
9/22-26/69	26.0	8.0	<0.1	0.5	<0.1	0.2
9/29-10/3/69	22.5	8.3	<0.1	0.5	<0.1	0.2
10/7-10/69	22.5		<0.1	0.5	<0.1	0.1
10/14-17/69	23.5	7.5	2.4	0.5	<0.1	<0.1
10/20-23/69	-	8.0	2.0	0.5	<0.1	0.6
10/28-31/69	18.6	8.8	0.7	0.5	<0.1	0.3
11/3-7/69	-	7.6	-	0.5	-	-
11/10-14/69	-	7.7	-	0.5	-	-
11/17-20/69	-	6.1	1.5	0.5	-	-
11/24-28/69	23.5	6.8	<0.1	0.5	-	-
12/1-4/69	26.8	7.2	<0.1	0.5	-	-
12/6-11/69	Control system not operating					
12/11-16/69						
12/18-23/69						
Average	23.6	8.1	0.9	0.7	0.1	0.29
Range	18.6-28.0	6.1-10.7	0.1-2.4	0.5-1.5	-	.1-.5

Table A-3
(continued)

Weekly Composite Metal Results for Test Final Effluent (System No. 2)

Baltimore Phosphate Removal Study

Date	Calcium mg/L	Magnesium mg/L	Iron mg/L	Aluminum mg/L	Copper mg/L	Zinc mg/L
7/14-17/69	22.3	9.1	0.8	< 0.5	< 0.1	0.2
7/22-25/69	25.0	10.7	1.9	1.0	0.2	0.5
7/28-31/69	25.0	10.7	0.6	1.5	<0.1	0.2
8/4-8/69	25.0	8.2	0.7	3.5	0.1	0.3
8/11-15/69	24.0	7.7	0.6	1.5	<0.1	0.3
8/18-22/69	22.0	6.5	0.5	2.5	<0.1	0.3
8/25-29/69	21.5	7.0	1.0	0.7	0.1	0.3
9/2-5/69	-	-	1.0	< 0.5	0.1	0.3
9/8-12/69	19.2	7.8	0.8	0.5	< 0.1	0.2
9/15-19/69	23.2	7.8	0.8	0.5	< 0.1	0.2
9/22-26/69	23.5	8.3	< 0.1	< 0.5	< 0.1	0.1
9/29-10/3/69	23.5	8.0	< 0.1	< 0.5	< 0.1	0.1
10/7-10/69	25.5	-	< 0.1	< 0.5	< 0.1	0.1
10/14-17/69	22.0	8.0	< 0.1	< 0.5	< 0.1	0.1
10/20-23/69	-	9.8	1.1	< 0.5	0.1	0.3
10/28-31/69	19.0	12.4	2.1	0.5	0.1	0.4
11/3-7/69	-	8.3	1.3	<0.5	-	-
11/10-14/69	-	9.0	0.6	< 0.5	-	-
11/17-20/69	-	7.7	0.9	< 0.5	-	-
11/24-28/69	23.0	7.9	0.1	< 0.5	-	-
12/1-4/69	24.8	7.4	0.1	< 0.5	-	-
12/6-11/69	25.0	9.2	< 0.1	< 0.5	-	-
12/11-16/69	24.0	12.2	0.1	<0.5	-	-
12/18-23/69	22.5	12.2	0.1	< 0.5	-	-
Average	23.2	8.9	0.7	0.8	0.1	0.24
Range	19.0-25.5	6.5-12.4	.1-2.1	0.5-3.5	-	0.1-0.5

Table A-3
(continued)

Weekly Composite Metal Results for Control Aeration Tank Outlet (System No. 1)

Baltimore Phosphate Removal Study

Date	Calcium mg/L	Magnesium mg/L	Iron mg/L	Aluminum mg/L	Copper mg/L	Zinc mg/L
7/7-11/69	34.8	25.0	27.0	14.3	3.2	5.5
7/14-17/69	48.6	28.6	27.7	17.7	4.4	8.4
7/22-25/69	90.0	27.5	23.0	8.5	1.0	9.5
7/29-31/69	83.0	30.0	16.8	8.5	3.0	7.6
8/4-8/69	86.0	32.7	20.0	14.5	4.0	-
8/11-15/69	49.5	28.0	10.3	8.5	3.2	7.2
8/18-22/69	47.5	28.0	-	5.5	3.8	8.1
8/25-29/69	-	31.0	24.0	22.0	4.6	6.1
9/2-5/69	-	40.0	36.0	33.0	5.2	9.0
9/8-12/69	49.0	23.7	-	-	4.6	10.0
9/15-19/69	38.5	26.3	-	-	3.2	6.7
9/20-26/69	-	28.0	30.0	26.5	3.4	6.3
9/29-10/3/69	31.0	28.0	35.2	-	5.5	11.0
10/7-10/69	35.0	25.5	21.2	19.0	5.6	7.3
10/14-17/69	38.0	31.0	23.6	17.5	5.2	10.0
10/20-23/69	-	31.0	25.0	16.0	1.3	6.6
10/28-31/69	-	35.6	24.4	16.0	1.2	5.5
11/3-7/69	-	31.5	14.0	11.0	-	-
11/10-14/69	-	33.0	25.0	11.5	-	-
11/17-20/69	-	31.3	27.4	8.5	-	-
11/24-28/69	65.0	34.6	30.5	21.8	-	-
12/1-4/69	-	34.6	26.5	13.3	-	-
12/6-11/69						
12/11-16/69		(Control System Not Operating)				
12/18-23/69						
Average	53.3	30.2	24.6	15.4	3.7	7.8
Range	31.0-90.0	23.7-40.0	10.3-36.0	5.5-33.0	1.0-5.6	5.5-11.0

Table A-3
(continued)

Weekly Composite Metal Results for Test Aeration Tank Outlet (System No. 2)

Baltimore Phosphate Removal Study

Date	Calcium mg/L	Magnesium mg/L	Iron mg/L	Aluminum mg/L	Copper mg/L	Zinc mg/L
7/7-11/69	41.6	25.5	30.0	26.8	4.2	7.5
7/14-17/69	51.7	18.0	11.5	10.8	3.2	7.0
7/22-25/69	49.5	19.7	11.5	8.0	3.1	13.7
7/29-31/69	-	32.0	27.0	14.0	4.2	9.5
8/4-8/69	64.0	27.5	25.2	13.0	2.3	-
8/11-15/69	46.0	25.0	-	4.5	3.1	6.5
8/18-22/69	36.5	18.5	-	5.7	-	5.7
8/25-29/69	47.5	34.0	-	9.1	6.6	9.2
9/2-5/69	30.0	46.5	36.0	44.0	7.2	11.5
9/8-12/69	40.0	25.7	8.8	5.7	3.5	6.7
9/15-19/69	44.0	24.5	-	12.3	2.2	6.2
9/20-26/69	27.5	21.3	31.5	31.5	4.0	7.0
9/29-10/3/69	-	39.5	15.0	37.5	5.2	9.5
10/7-10/69	32.8	29.5	23.6	21.0	5.4	7.6
10/14-17/69	34.5	28.0	56.0	19.0	4.9	6.5
10/20-23/69	-	25.2	29.2	16.0	1.8	7.7
10/28-31/69	-	-	23.8	9.4	1.9	5.5
11/2-7/69	-	32.2	15.2	11.0	-	-
11/10-14/69	-	32.8	24.5	12.5	-	-
11/17-20/69	-	25.5	26.8	9.0	-	-
11/24-28/69	-	24.0	16.0	12.2	-	-
12/1-4/69	-	31.6	24.0	13.5	-	-
12/6-11/69	74.0	38.8	33.0	18.0	-	-
12/11-16/69	-	48.0	35.0	16.4	-	-
12/18-23/69	-	29.0	27.2	13.0	-	-
Average	44.0	28.2	25.3	15.7	3.9	8.0
Range	27.5-74.0	18.0-48.0	8.8-56.0	4.5-44.0	1.8-7.2	5.5-11.5

Table A-3
(continued)

Weekly Composite Metal Results for Control Return Sludge (System No. 1)
Baltimore Phosphate Removal Study

Date	Calcium mg/L	Magnesium mg/L	Iron mg/L	Aluminum mg/L	Copper mg/L	Zinc mg/L
7/17-11/69	121	92	100	90	23	37
7/14-17/69	131	60	87	75	18	35
7/22-25/69	168	142	-	-	14	40
7/29-31/69	120	-	-	-	12	23
8/4-8/69	165	80	-	-	15	28
8/11-15/69	92	42	-	-	18	34
8/18-22/69	-	121	164	-	-	43
8/25-29/69	80	97	50	61	23	30
9/2-5/69	-	67	66	66	11	19
9/8-12/69	-	131	218	115	20	48
9/15-19/69	138	89	-	-	14	38
9/20-26/69	101	104	124	123	19	33
9/29-10/3/69	73	115	160	133	24	42
10/7-10/69	-	-	43	40	-	-
10/14-17/69	79	106	124	81	24	41
10/20-23/69	-	83	110	80	7	29
10/28-31/69	-	192	122	88	12	31
11/3-7/69	-	140	132	115	-	-
11/10-7/69	-	110	98	38	-	-
11/17-20/69	-	120	122	65	-	-
11/24-28/69	145	110	89	39	-	-
12/1-4/69	118	92	67	32	-	-
12/6-11/69						
12/11-16/69	(CONTROL SYSTEM NOT OPERATING)					
12/18-23/69						
Average	118	105	110	78	17	34
Range	73-168	42-192	43-218	32-133	7-24	19-48

Table A-3
(continued)

Weekly Composite Metal Results for Test Return Sludge (System No. 2)

Baltimore Phosphate Removal Study

Date	Calcium mg/L	Magnesium mg/L	Iron mg/L	Aluminum mg/L	Copper mg/L	Zinc mg/L
7/7-11/69	148	63	51	50	24	40
7/14-17/69	102	55	83	61	19	37
7/22-25/69	165	-	-	-	-	38
7/29-31/69	160	69	80	-	15	38
8/4-8/69	198	95	-	-	16	40
8/11-15/69	98	46	-	30	-	19
8/18-22/69	74	37	-	20	-	20
8/25-29/69	107	100	-	47	25	-
9/8-12/69	101	88	-	-	12	36
9/15-19/69	104	100	133	61	14	30
9/20-26/69	59	145	103	110	-	24
9/29-10/3/69	62	91	121	105	17	33
10/7-10/69	-	79	109	78	14	25
10/14-17/69	77	147	190	110	27	46
10/20-23/69	-	83	122	76	8	31
10/28-31/69	-	94	119	96	11	26
11/3-7/69	-	102	103	50	-	-
11/10-7/69	-	86	89	33	-	-
11/17-20/69	-	89	122	70	-	-
11/24-28/69	-	69	53	27	-	-
12/1-4/69	135	93	70	26	-	-
12/6-11/69	145	129	92	33	-	-
12/11-16/69	-	122	89	41	-	-
12/18-23/69	-	70	60	34	-	-
Average	113	90	99	59	17	32
Range	59-198	37-147	53-190	20-110	8-27	19-40

Table A-4

Baltimore Phosphate Removal Study
Summary of Plant Samples
Ortho Phosphate - mg P/L

Date Submitted	1 Raw	2 Degritted	3 1^{o}Settled	4 2^{o} AS Eff.	5 TF Outlet	6 2^{o}TF Eff.	3-6 TF Removal Percent	3-4 AS Removal Percent
8/1/69	13.0	12.5	15.3	11.8	13.7	15.0	0	23
8/5/69	-	-	-	-	-	-	-	-
8/6/69	4.7	6.5	8.2	1.0	7.8	8.9	0	88
8/7/69	6.5	7.9	9.3	1.7	8.0	7.3	22	82
8/12/69	9.2	9.7	11.1	2.4	8.8	8.0	28	78
8/13/69	8.8	9.5	10.2	4.8	9.5	9.0	12	53
8/14/69	9.2	9.0	8.5	2.5	10.4	10.3	0	71
8/27/69	9.0	8.5	10.4	0.5	11.0	10.5	0	95
8/28/69	8.8	8.2	9.7	0.6	5.3	6.2	36	94
8/29/69	7.7	7.2	9.0	0.3	10.0	7.7	14	97
9/10/69	8.7	9.5	9.9	2.7	9.0	12.7	0	73
9/11/69	9.2	10.0	12.5	1.5	9.6	-	-	88
9/12/69	7.0	7.8	11.5	0.8	12.5	12.0	0	93
9/17/69	8.6	9.2	11.4	0.5	7.7	7.3	36	96
9/18/69	13.5	7.8	10.0	-	6.3	8.8	12	-
10/1/69	9.5	10.3	12.0	2.5	13.2	9.5	21	79
10/2/69	10.5	10.3	11.4	0.3	12.2	12.8	0	97
10/3/69	5.7	7.2	9.9	2.5	-	9.8	2	75
10/8/69	8.0	8.0	9.7	3.6	10.5	11.6	0	63
10/9/69	-	-	9.3	0.5	10.0	8.0	14	95
10/10/69	4.7	6.5	10.9	0.5	9.6	10.0	8	95
10/23/69	8.7		-	11.7	11.5	10.8	-	-
10/24/69	7.0	7.5	9.6	5.1	9.3	10.2	0	47
11/7/69	7.6	7.6	9.2	0.4	9.2	9.6	0	96
11/12/69	6.2	6.5	9.2	2.2	10.1	8.0	13	76
11/13/69	-	11.1	12.1	0.5	13.1	14.0	0	96
11/14/69	7.4	8.1	10.7	1.9	9.6	9.5	11	82
11/19/69	8.1	7.5	10.2	-	12.9	14.0	0	-
11/20/69	8.2	8.5	-	-	10.3	10.1	-	-
11/21/69	8.6	9.3	9.0	-	-	-	-	-
12/3/69	9.4	9.6	12.3	4.1	11.9	-	-	67
12/4/69	9.6	10.5	11.1	1.0	11.7	10.6	4	91
12/5/69	6.3	6.0	9.7	0.6	11.2	10.2	0	94
12/10/69	-	9.3	12.2	1.9	12.2	-	-	85
12/11/69	3.2	5.4	9.7	1.2	11.3	10.9	0	88
12/12/69	7.6	7.6	6.3	0.9	7.0	7.0	0	86
12/17/69	7.6	9.5	9.5	3.2	8.8	11.8	0	66
12/18/69	6.2	6.4	9.5	0.2	7.9	8.1	15	98
12/19/69	5.5	6.1	6.9	2.4	8.1	9.5	0	70
Average	8.0	8.4	10.2	2.3	10.1	10.0	8	81

Table A-4
(continued)
Baltimore Phosphate Removal Study
Summary of Plant Samples
Total Phosphate - mg P/L

Date Submitted	1 Raw	2 Degritted	3 1°Settled	4 2°AS Eff.	5 TF Outlet	6 2° TF Eff.	3-6 TF Removal Percent	3-4 AS Removal Percent
7/31/69	20.0	16.0	15.0	8.0	15.0	14.0	11	47
8/1/69	16.0	16.0	16.0	14.0	16.0	16.0	0	13
8/5/69	10.0	10.5	11.0	2.5	9.5	8.5	23	77
8/6/69	11.0	10.0	10.0	4.5	9.0	9.0	10	55
8/7/69	12.0	13.0	15.0	5.0	15.0	16.0	0	67
8/12/69	-	10.0	12.0	4.0	11.0	10.0	17	67
8/13/69	10.0	14.0	15.0	3.0	12.0	12.0	20	80
8/14/69	15.0	18.0	-	7.0	15.0	18.0	0	59
8/20/69	20.0	16.0	13.5	3.5	15.0	14.0	0	74
8/21/69	8.0	9.5	10.5	2.0	13.0	13.0	0	81
8/22/69	13.5	15.5	13.5	1.0	8.5	8.0	14	93
9/3/69	6.5	7.0	9.5	1.5	10.5	9.5	0	84
9/4/69	7.5	12.0	10.0	2.0	8.5	9.0	10	80
9/5/69	6.0	5.5	9.4	1.5	7.5	7.5	20	84
9/10/69	13.0	16.4	15.5	3.8	12.8	15.0	3	75
9/11/69	10.8	11.5	15.5	2.0	11.5	13.0	16	87
9/12/69	10.0	-	-	-	13.6	12.8	-	-
9/24/69	9.4	12.2	13.0	1.0	13.6	12.6	3	92
9/25/69	11.4	13.4	12.2	1.0	8.5	9.4	23	92
9/26/69	9.4	9.8	12.2	1.0	11.0	10.0	18	92
10/3/69	-	-	9.9	2.8	-	9.8	1	72
10/15/69	16.6	18.4	13.0	2.7	12.5	13.2	1	79
10/16/69	11.6	11.4	13.2	-	10.2	11.6	12	-
10/17/69	9.1	8.8	13.2	1.0	12.4	11.6	12	92
10/23/69	9.7	9.6	11.5	12.4	11.7	-	-	0
10/24/69	8.5	9.4	10.7	5.5	9.6	11.2	0	45
10/29/69	9.0	7.8	11.4	3.9	11.2	11.0	0	66
10/30/69	7.5	9.0	10.2	4.8	9.0	7.2	29	53
10/31/69	10.0	10.8	11.1	4.7	10.2	8.7	22	58
11/5/69	8.6	7.4	9.8	0.8	10.1	-	-	92
11/6/69	6.6	7.0	9.6	0.7	11.4	9.1	5	93
11/7/69	8.8	8.4	9.6	0.6	-	9.7	0	94
11/12/69	12.6	11.0	13.2	2.4	10.6	10.7	11	82
11/13/69	10.8	11.6	12.2	0.8	13.8	14.8	0	93
11/14/69	-	-	-	2.6	10.5	-	-	70
11/19/69	9.8	13.2	13.6	3.2	14.6	14.0	0	76
11/20/69	10.0	10.4	-	-	14.4	10.6	-	-
11/21/69	11.0	-	-	-	11.0	10.6	-	-
11/26/69	13.0	13.4	14.6	3.2	12.0	12.8	12	78
11/28/69	11.8	-	15.4	2.0	18.8	11.8	23	87
12/3/69	10.8	11.4	13.6	4.8	12.4	12.2	10	65
12/4/69	10.5	11.6	11.8	1.8	11.8	10.8	8	85
12/5/69	9.0	9.0	11.0	1.2	11.5	11.0	0	89
12/10/69	10.0	11.0	12.4	2.8	13.0	11.6	6	77
12/11/69	4.5	8.4	12.6	2.0	11.2	-	-	84
12/12/69	8.4	8.8	7.8	1.4	7.0	-	-	82
Average	10.6	11.3	12.2	3.2	11.7	11.5	9	74

Table A-4
(continued)

Baltimore Phosphate Removal Study
Summary of Plant Samples
Ammonia Nitrogen - mg N/L

Date Submitted	1 Raw	2 Degritted	3 1°Settled	4 2° ASEff.	5 TF Outlet	6 2°TF Eff.	3-6 TF Removal Percent	3-4 AS Removal Percent
7/31/69	11.0	15.2	13.4	11.0	14.7	15.0	0	18
8/1/69	17.2	20.5	19.0	11.7	26.0	18.5	3	38
8/5/69	15.3	17.0	18.4	12.5	22.5	20.0	0	32
8/6/69	11.7	17.5	20.0	13.0	21.0	22.5	0	35
8/27/69	21.2	17.5	22.0	11.9	15.5	16.0	27	46
8/28/69	12.2	13.0	-	10.1	16.4	18.1	-	-
8/29/69	13.7	14.8	16.9	10.7	15.8	-	-	37
9/10/69	14.5	18.3	18.8	10.9	17.5	16.3	13	42
9/11/69	14.2	15.0	15.9	6.7	17.7	17.5	0	58
9/12/69	14.2	13.0	18.7	3.0	19.4	18.5	1	84
9/17/69	16.4	16.6	27.0	10.0	22.0	19.4	28	63
9/18/69	17.8	20.5	26.9	8.2	22.3	17.8	34	70
9/19/69	20.8	24.5	29.5	8.8	36.5	18.5	37	70
10/1/69	16.7	19.2	21.5	14.0	18.9	20.0	7	35
10/2/69	17.3	19.2	18.8	12.5	18.0	20.0	0	34
10/3/69	19.5	22.0	26.0	14.2	20.7	19.0	27	45
10/23/69	23.5	28.4	24.6	15.2	-	-	-	38
10/24/69	22.0	28.0	-	-	-	-	-	-
10/29/69	19.3	20.0	22.1	-	18.7	21.0	5	-
10/30/69	20.5	23.0	23.5	-	19.1	-	-	-
10/31/69	24.7	25.4	28.0	17.5	22.4	-	-	38
11/5/69	16.3	16.8	20.7	16.1	19.8	18.5	10	22
11/6/69	17.7	18.5	18.7	13.8	16.9	17.2	8	26
11/7/69	-	-	-	-	17.7	19.1	-	-
11/12/69	19.5	20.8	26.0	14.9	-	-	-	43
11/13/69	23.9	24.2	-	-	-	-	-	-
11/14/69	28.0	-	-	-	-	-	-	-
11/19/69	-	20.8	26.6	18.3	23.8	-	-	31
11/20/69	26.1	22.9	-	-	22.1	19.8	-	-
11/21/69	21.4	22.5	-	-	19.0	17.4	-	-
12/10/69	22.3	20.7	26.7	15.2	23.5	-	-	43
12/11/69	16.6	19.8	25.7	13.6	-	18.3	29	47
12/12/69	19.6	19.4	23.1	12.1	17.0	16.6	28	48
12/17/69	27.3	29.1	27.2	18.6	22.4	-	-	32
12/18/69	20.1	19.3	24.8	18.6	20.4	20.3	18	25
12/19/69	28.8	30.3	25.4	16.7	22.4	20.1	26	34
Average	18.7	20.4	22.6	12.9	20.3	18.6	14	42

Table A-4
(continued)

Baltimore Phosphate Removal Study
Summary of Plant Samples
Total Kjeldahl Nitrogen - mg N/L

Date Submitted	1 Raw	2 Degritted	3 1°Settled	4 2°AS Eff.	5 TF Outlet	6 2°TF Eff.	3-6 TF Removal Percent	3-4 AS Removal Percent
7/31/69	36.0	40.0	32.0	20.0	32.0	28.0	13	38
8/1/69	35.0	42.0	38.0	18.0	38.0	28.0	26	53
8/5/69	26.0	29.0	30.0	13.0	28.0	23.0	23	57
8/6/69	24.0	23.0	23.5	-	21.0	23.0	2	
8/7/69	24.0	28.0	30.0	17.0	25.0	25.0	17	43
8/12/69	18.0	19.0	19.5	13.5	19.5	15.0	23	31
8/13/69	20.0	24.0	24.0	14.0	20.0	20.0	17	42
8/14/69	22.5	27.0	23.5	16.5	22.0	21.0	11	30
8/21/69	29.0	31.0	32.0	24.0	32.0	30.0	6	25
8/22/69	30.0	34.0	33.0	19.0	26.0	25.0	24	43
9/3/69	17.8	30.0	24.0	4.0	23.0	19.0	21	83
9/4/69	21.0	27.0	25.0	6.8	21.0	20.0	20	73
9/5/69	18.5	17.0	26.0	6.4	21.0	21.5	17	75
9/10/69	29.5	35.0	34.0	13.5	28.0	27.0	21	60
9/11/69	29.5	31.0	32.0	9.8	28.5	27.5	14	69
9/12/69	30.0	-	-	-	29.0	27.5	-	-
9/24/69	27.8	33.0	31.0	14.0	27.6	28.5	8	55
9/25/69	31.0	40.0	23.0	12.0	22.2	19.6	15	48
9/26/69	26.2	27.0	30.0	14.0	25.0	25.4	15	53
10/2/69	-	-	-	1.0	-	-	-	-
10/3/69	-	-	9.9	-	-	9.8	1	-
10/8/69	20.0	18.2	21.0	10.4	14.2	16.6	21	50
10/9/69	-	-	18.8	9.0	9.2	13.4	29	52
10/10/69	12.2	13.8	14.2	8.2	15.8	15.6	-	42
10/23/69	-	-	-	24.8	23.5	20.8	-	-
10/24/69	-	-	21.3	11.0	19.2	22.5	-	54
10/29/69	26.5	27.9	33.3	16.2	-	21.0	37	51
10/30/69	28.8	38.1	33.9	15.6	21.6	21.6	36	54
10/31/69	27.3	27.9	-	20.4	-	20.7	-	-
11/6/69	24.0	23.8	24.0	18.0	-	18.8	22	25
11/7/69	27.0	27.2	24.2	14.0	-	-	-	42
11/12/69	33.0	30.5	28.2	-	18.6	19.4	31	-
11/13/69	-	-	23.4	15.0	20.8	22.6	3	36
11/14/69	-	17.0	21.6	14.0	20.2	17.8	18	35
11/19/69	24.6	36.0	-	18.4	28.2	23.4	38	52
11/20/69	27.8	32.0	-	-	26.4	-	-	-
11/21/69	26.4	-	-	-	20.4	20.0	-	-
11/26/69	31.5	32.0	-	31.0	22.0	17.4	49	9
11/28/69	33.0	-	34.0	16.8	35.0	21.6	36	51
12/3/69	30.0	32.0	34.0	17.4	19.4	19.6	42	49
12/4/69	22.4	27.8	28.8	13.2	20.8	20.2	30	54
12/5/69	31.0	31.0	28.8	14.8	23.8	23.2	19	49
12/10/69	23.5	24.0	25.0	17.0	23.5	21.4	14	32
12/11/69	20.6	24.0	26.0	16.8	23.5	21.8	16	35
12/12/69	22.6	23.5	24.0	14.0	18.0	17.0	42	42
Average	26	28.4	26.6	14.7	22.9	21.4	21.6	47.1

Table A-4
(continued)

Baltimore Phosphate Removal Study
Summary of Plant Samples
Total Carbon - mg C/L

Date Submitted	1 Raw	2 Degritted	3 1^{o}Settled	4 2^{o}AS Eff.	5 TF Outlet	6 2^{o}TF Eff.	3-6 TF Removal Percent	3-4 AS Removal Percent
7/31/69	255	280	225	125	180	170	24	44
8/1/69	370	365	335	140	215	215	36	58
8/5/69	145	150	145	75	100	110	24	48
8/6/69	135	160	165	80	105	110	33	52
8/7/69	135	145	150	70	105	100	33	53
8/27/69	175	160	190	80	120	125	34	58
8/28/69	175	150	175	75	100	95	46	57
8/29/69	170	205	175	70	120	115	34	60
9/17/69	135	135	135	60	95	85	37	55
9/18/69	130	165	140	55	75	75	46	61
9/19/69	140	140	160	60	75	80	50	63
10/1/69	85	95	110	60	75	70	36	45
10/2/69	95	100	100	60	80	95	5	40
10/3/69	120	135	165	70	100	95	42	58
10/15/69	105	115	110	60	90	80	27	45
10/16/69	125	130	140	80	85	-	-	43
10/17/69	120	120	155	60	95	95	39	61
10/23/69	105	115	115	60	85	80	30	48
10/24/69	115	120	125	75	80	80	36	40
10/29/69	125	105	125	65	70	75	40	48
10/30/69	140	140	140	70	75	70	50	50
10/31/69	180	190	145	95	90	90	38	34
11/5/69	75	75	80	55	60	60	25	31
11/6/69	85	85	90	55	60	50	44	39
11/7/69	150	150	125	55	60	65	48	56
11/12/69	85	90	110	65	85	65	41	41
11/13/69	105	130	120	60	75	85	29	50
11/14/69	140	140	130	65	80	80	38	50
12/3/69	140	125	140	70	90	90	36	50
12/4/69	125	125	135	60	95	85	37	56
12/5/69	135	135	135	70	95	85	37	48
12/17/69	120	125	120	60	70	70	42	50
12/18/69	115	110	120	60	45	65	46	50
12/19/69	160	165	130	60	85	75	42	54
Average	139	143	143	70	92	90	37	50

Table A-4
(continued)

Baltimore Phosphate Removal Study
Summary of Plant Samples
COD mg/L

Date Submitted	1 Raw	2 Degritted	3 1°Settled	4 2°AS Eff.	5 TF Outlet	6 2°TF Eff.	3-6 TF Removal Percent	3-4 AS Removal Percent
7/31/69	550	580	520	180	260	250	52	65
8/1/69	520	490	490	170	280	220	55	65
8/5/69	230	250	250	70	150	150	40	72
8/6/69	260	290	290	90	180	140	52	69
8/7/69	310	350	310	130	210	180	42	58
8/27/69	195	205	215	50	170	155	28	77
8/28/69	190	210	200	65	120	125	38	68
8/29/69	200	225	200	75	160	155	23	63
9/10/69	220	230	220	60	140	145	34	73
9/11/69	245	240	245	65	110	150	39	73
9/12/69	230	230	240	60	140	140	42	75
9/17/69	-	300	300	105	160	140	53	65
9/18/69	370	370	380	75	110	105	72	80
9/19/69	390	395	390	90	150	170	56	77
10/1/69	170	175	210	65	130	125	40	69
10/2/69	200	210	205	70	150	155	24	66
10/3/69	220	240	235	75	170	155	34	68
10/8/69	130	130	150	45	70	70	53	70
10/9/69	-	-	160	35	85	80	50	78
10/10/69	115	215	240	40	195	110	54	83
10/15/69	115	125	125	20	85	75	40	84
10/16/69	150	150	140	85	70	-	-	40
10/17/69	130	130	220	20	100	100	55	91
10/23/69	250	250	250	55	120	100	60	78
10/24/69	260	240	240	60	110	120	50	75
11/5/69	100	75	65	45	60	55	15	31
11/6/69	85	95	105	40	60	60	43	62
11/7/69	240	235	180	40	80	80	55	78
11/12/69	95	95	145	50	75	85	41	65
11/13/69	150	170	165	45	100	90	45	73
11/14/69	225	260	205	65	90	95	54	69
11/19/69	100	95	100	45	75	80	-	55
11/20/69	105	100	-	-	65	75	-	-
11/21/69	165	205	-	-	65	80	-	-
12/3/69	205	150	190	45	75	80	50	76
12/4/69	160	175	195	40	90	70	64	79
12/5/69	195	185	200	45	95	85	58	78
12/10/69	210	90	130	50	80	65	50	92
12/11/69	50	65	75	50	70	65	13	33
12/12/69	100	100	70	40	50	60	14	43
12/17/69	235	260	230	80	80	85	63	65
12/18/69	235	215	230	55	75	80	65	76
12/19/69	360	400	280	50	125	110	61	83
Average	211	219	219	64	117	112	46	69

Table A-4
(continued)

Baltimore Phosphate Removal Study
Summary of Plant Samples
Combined Nitrate-Nitrite - mg N/ℓ

Date Submitted	1 Raw	2 Degritted	3 1^oSettled	4 2^oAS Eff.	5 TF Outlet	6 2^oTF Eff.	3-6 TF Increase Times	3-4 AS Increase Times
7/31/69	0.10	0.10	0.10	0.15	0.90	1.10	11	1
8/27/69	0.10	0.10	0.10	1.4	0.40	0.30	4	14
8/28/69	0.05	0.05	2.80	.80	2.80	3.00	0	0
8/29/69	0.10	0.10	0.05	2.90	2.10	2.95	59	58
9/17/69	0.10	0.10	0.15	2.20	0.20	0.10	0	15
9/18/69	0.10	0.20	0.25	3.00	.20	0.95	4	12
9/19/69	0.10	0.10	0.20	3.10	1.70	1.70	9	16
10/1/69	0.10	0.10	0.10	1.80	0.10	1.10	11	18
10/2/69	0.10	0.10	0.10	2.30	0.10	0.60	6	23
10/3/69	0.10	0.10	0.10	3.10	0.70	2.70	27	31
10/8/69	0.10	0.10	0.10	3.40	0.20	0.80	8	34
10/9/69	-	-	0.10	1.90	1.70	2.40	24	19
10/10/69	0.10	0.10	0.10	1.70	2.50	2.10	21	17
10/15/69	0.10	0.10	0.10	1.30	0.10	0.10	0	13
10/16/69	0.10	0.10	0.10	1.40	0.70	-	-	14
10/17/69	0.10	0.10	0.10	1.20	1.00	1.10	11	12
10/29/69	0.10	0.10	.10	0.8	2.4	2.9	29	8
10/30/69	0.10	0.10	.10	0.8	2.1	3.0	30	8
10/31/69	0.10	0.10	.10	0.7	1.7	1.4	14	7
11/19/69	0.25	0.13	-	2.2	0.25	2.4	-	-
11/20/69	0.18	0.18	-	-	0.25	4.0	-	-
11/21/69	0.15	0.15	-	-	2.6	3.6	-	-
12/3/69	0.10	0.10	0.20	0.10	0.10	0.10	0	0
12/4/69	0.10	0.10	0.20	0.10	0.10	0.10	0	0
12/5/69	0.10	0.10	0.10	0.15	1.4	2.9	1	29
12/17/69	0.10	0.10	0.10	0.25	0.75	1.8	2	18
12/18/69	0.10	0.10	0.10	0.25	1.7	1.7	2	17
12/19/69	0.25	0.25	-	0.50	0.80	1.4	-	-
Average	0.11	0.11	0.23	1.45	1.06	1.71	12	16

Table A-5

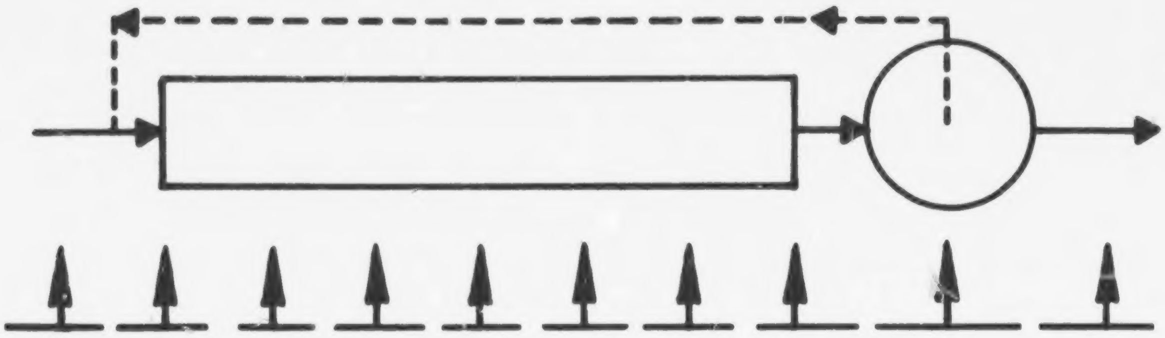
Baltimore Phosphate Removal Study

Average Test Period Results

Parameter	Test Period																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17	19	Average
Common PE BOD_5, mg/L	208	270	188	155	148	179	220	132	178	118	187	161	190	173	178	140	200	178
Common PE SS, mg/L	125	154	110	123	163	173	176	171	154	163	144	142	143	133	102	104	88	139
Common PE COD_A, mg/L	175	230	340	268	235	235	300	215	---	280	245	265	300	305	282	270	280	264
Common PE Tot. Carbon, mg/L	---	---	270	141	135	113	141	159	181	112	173	167	[illegible]	172	156	157	139	159
Common PE Tot. P, mg/L	10.1	12.2	12.6	10.4	8.4	13.2	11.3	11.8	10.1	12.0	13.4	10.9	11.7	10.8	10.6	10.8	11.7	11.3
Common PE Ortho PO_4, mg/L	8.4	9.8	8.8	7.8	7.1	8.0	9.3	9.5	9.9	10.8	11.5	10.5	10.6	9.7	9.0	8.8	8.6	9.2
Common PE Kjeldahl N, mg/L	13.0	27.0	28.1	24.5	23.0	23.9	27.6	28.4	35.4	37.1	26.5	---	30.2	37.9	31.9	28.5	28.4	28.2
Common PE Ammonia N, mg/L	9.8	14.1	15.8	17.2	19.7	17.7	18.5	23.9	34.1	29.2	24.3	35.3	28.2	32.8	29.5	26.5	27.9	23.8
Common PE pH, units	6.3	6.2	6.5	6.5	6.4	6.5	6.5	6.4	6.1	6.5	6.2	6.4	6.3	6.5	6.4	6.0	6.2	6.3
Control PE Flow, mgd	8.0	8.8	8.9	8.0	7.7	9.4	7.8	10.4	9.1	9.1	9.6	10.7	8.5	9.1	---	---	---	8.9
Control Return Sludge, % PE	22	21	23	26	25	19	36	19	22	22	21	19	23	22	---	---	---	22.8
Control Sludge Wasting, % PE	1.8	1.4	1.2	1.9	3.0	1.8	2.5	1.7	2.5	2.4	2.2	1.8	2.6	2.2	---	---	---	2.0
Control A.T. MLSS, mg/L	2,290	2,160	2,200	2,040	2,240	2,280	2,140	2,020	2,190	1,830	1,970	1,940	1,960	1,990	---	---	---	2,086
Control A.T. VSS/SS, %	73	73	75	73	68	69	71	72	72	76	77	74	86	---	---	---	---	73
Control R.S. SS, mg/L	11,000	9,140	10,330	9,400	7,800	10,200	9,150	9,700	8,200	7,200	8,400	8,900	8,400	---	---	---	---	9,063
Control Secondary Effluent SS, mg/L	7	9	21	11	7	6	11	18	14	16	11	11	11	11	---	---	---	11
Control BOD_5 Loading, lb/day/lb SS	0.28	0.42	0.26	0.23	0.20	0.28	0.31	0.26	0.28	0.23	0.35	0.34	0.32	0.32	---	---	---	0.29
Control Air Supplied, scfm/gal. PE	1.25	1.23	1.19	1.52	2.10	1.54	1.68	1.28	1.27	1.32	1.38	1.16	1.68	1.27	---	---	---	1.42
Control Sludge Production, lb Wasted/lb BOD_5(R)	1.16	0.51	0.76	1.24	1.10	1.28	1.19	1.50	1.19	1.63	1.03	1.05	1.22	---	---	---	---	1.14
Control BOD_5 Removed, %	82	92	87	93	90	80	89	83	97	90	96	95	94	94	---	---	---	90
Control Tot. Carbon Removed, %	---	---	44	53	69	49	65	65	63	48	60	59	62	58	---	---	---	58
Control COD_A Removed, %	67	81	72	69	79	74	82	74	---	82	78	80	82	84	---	---	---	77
Control Tot. P Removed, %	80	43	52	73	85	78	84	73	91	47	92	94	90	84	---	---	---	77
Control Ortho PO_4 Removed, %	81	41	43	78	96	87	90	72	96	51	97	95	95	87	---	---	---	82
Control P in Waste Sludge SS, %	2.4	2.7	3.5	4.4	5.0	3.7	4.6	4.1	5.1	3.7	4.9	5.8	5.5	---	---	---	---	4.3
Control Est. P Removal in Wasted Sludge, %	46	28	39	76	93	54	93	57	105	54	68	84	102	---	---	---	---	70
Control Tot. Kjeldahl N Removed, %	26	41	35	-36	59	40	49	39	---	39	28	---	36	49	---	---	---	40
Control Ammonia N Removed, %	4	40	29	26	54	48	50	44	35	43	29	49	38	45	---	---	---	38
Control SE Nitrite + Nitrate, mg/L	0.2	---	0.1	0.2	2.8	1.6	1.5	0.9	0.2	0.6	0.3	0.1	0.1	1.2	---	---	---	0.75
Control SE pH, units	6.7	6.7	7.0	7.0	6.9	6.9	7.0	7.1	6.9	7.2	7.0	7.1	7.1	7.0	---	---	---	7.0
Test PE Flow	8.7	8.9	9.0	7.0	7.0	4.7	8.5	5.3	9.5	8.8	9.7	5.4	9.0	9.3	19.3	16.9	8.0	9.1
Test Return Sludge, % PE	21	21	22	28	44	32	27	38	16	23	21	37	22	22	23	24	52	28
Test Sludge Wasting, % PE	1.6	1.1	1.1	3.1	1.2	3.8	4.0	2.9	1.7	2.0	2.0	2.4	2.1	1.6	[illegible]	1.7	3.5	2.2
Test A.T. MLSS, mg/L	2,210	2,130	2,080	1,490	3,060	2,230	1,990	1,880	2,030	1,850	1,980	1,990	1,900	1,940	2,160	2,120	1,620	2,033
Test A.T. VSS/SS, %	73	74	78	74	67	68	73	71	73	77	76	72	75	---	77	73	76	74
Test R.S. SS, mg/L	8,300	8,190	10,310	6,800	9,500	8,900	6,600	6,600	9,000	7,500	6,900	7,300	8,000	---	10,900	9,700	4,200	8,000
Test Secondary Effluent SS, mg/L	10	11	20	12	11	5	9	7	14	14	21	15	10	10	10	18	7	12
Test BOD_5 Loading, lb/day/lb SS	0.32	0.43	0.31	0.28	0.13	0.14	0.37	0.14	0.32	0.22	0.36	0.17	0.35	0.32	0.61	0.54	0.38	0.32
Test Air Supplied, scfm/gal PE	1.21	0.95	1.05	1.58	2.45	3.42	1.70	2.68	1.83	1.42	1.27	2.65	1.29	1.40	1.15	1.25	1.51	1.69
Test Sludge Production, lb Wasted/lb BOD_5(R)	0.77	0.38	0.72	1.46	0.89	2.10	1.30	1.60	0.89	1.55	0.82	1.12	0.94	---	1.09	1.28	0.78	1.10
Test BOD_5 Removed, %	83	89	82	93	87	85	92	90	96	82	90	96	94	95	90	92	96	90
Test Tot. Carbon Removed, %	---	---	38	52	65	62	53	62	63	46	57	60	59	58	57	63	58	57
Test COD_A Removed, %	64	76	63	66	78	78	80	74	---	76	69	80	80	84	78	80	79	75
Test Tot. P Removed, %	80	16	22	54	83	86	86	89	86	18	39	94	55	85	88	78	32	63
Test Ortho PO_4 Removed, %	81	34	10	34	95	92	91	92	90	31	37	97	57	88	90	83	30	65
Test P in Waste Sludge SS, %	2.5	3.0	2.7	4.2	4.4	4.4	4.3	4.9	4.9	3.4	2.6	5.7	4.9	---	5.5	5.8	4.3	4.3
Test Est. P Removal in Wasted Sludge, %	32	25	24	85	60	82	101	79	74	43	27	92	77	---	91	79	54	68
Test Tot. Kjeldahl N Removed, %	31	37	31	34	54	67	55	40	---	32	29	---	33	48	37	35	30	39
Test Ammonia N Removal, %	15	22	23	23	49	72	47	44	34	37	28	36	35	44	36	36	44	37
Test SE Nitrite + Nitrate, mg/L	0.1	---	0.1	0.1	2.4	3.0	1.8	1.3	0.2	0.2	0.3	0.3	0.1	0.4	0.7	0.1	0.1	0.7
Test SE pH, units	6.8	6.8	7.0	7.1	6.9	6.8	7.0	7.0	7.0	7.3	6.9	7.3	7.0	7.1	6.9	6.7	6.9	7.0

Table A-6

PROFILE ANALYTICAL RESULTS



	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
1. Normal Control System 2/28/70 - 10:00 p.m., MLSS = 1860, P/SS = 4.6										
D.O. mg/L	0.0	-	-	-	-	-	-	5.6	-	-
pH	6.2	6.5	6.5	6.5	6.6	6.6	6.7	6.7	6.5	6.8
Sol.COD mg/L	435	205	120	100	100	87	85	80	135	85
Ortho PO_4 mg/L	8.6	16.2	16.1	14.1	10.1	6.6	3.6	2.2	10.9	0.5
Sol.Tot.P mg/L	16.6	24.0	21.1	17.3	11.4	7.6	3.8	2.6	12.3	0.8
Tot.P mg/L	20.1	99	102	97	94	90	88	87	340	1.0
Sol.Tot.KN mg/L	27.1	25.8	23.6	21.8	21.0	20.7	19.8	19.0	20.6	16.9
Tot.KN mg/L	32.0	138	150	153	148	144	140	142	505	17.0
Sol.Mg mg/L	9.8	14.6	12.8	14.8	11.6	12.4	10.4	10.8	13.4	9.2
Tot.Mg mg/L	-	21.2	26.8	28.0	28.0	25.6	25.2	28.8	75.2	
Sol.Ca mg/L	30.0	30.6	29.0	27.0	26.6	26.6	28.0	26.6	29.0	30.0
Tot.Ca mg/L	-	57.0	60.0	57.0	80.0	74.0	50.0	77.0	110	-
Sol.Fe mg/L	1.52	0.58	-	-	-	-	-	0.45	-	-
Tot.Fe mg/L	-	24.0	32.4	32.0	30.0	29.6	27.6	29.6	121	-
2. Normal Control System 2/13/70 - 10:30 a.m., MLSS = 2110										
D.O. mg/L	0.0	-	-	-	-	-	-	5.9	-	-
Sol.COD mg/L	308	140	80	60	65	55	50	55	85	65
Ortho PO_4 mg/L	4.9	7.2	6.0	4.3	3.3	2.5	1.7	1.2	7.9	1.9
Sol.Tot.P mg/L	7.0	8.4	6.6	4.5	3.5	2.5	1.8	1.2	8.6	2.1
Sol.Tot.KN mg/L	22.0	17.2	15.1	13.0	12.6	12.0	11.5	11.2	13.5	12.2
Sol.Mg mg/L	11.7	13.2	11.2	10.8	9.9	9.6	9.4	9.2	10.7	9.5
Sol.Ca mg/L	31.4	32.0	31.4	31.0	31.0	31.4	31.4	31.4	31.0	31.0
Sol.Fe mg/L	0.26	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	.1
3. Contact Stabilization Test System 12/22/69 - 10:00 a.m.										
D.O. mg/L	0.0	1.6	2.5	3.0	0.7	5.0	7.3	8.0	0.0	4.0
pH	6.7	6.9	6.8	6.9	6.9	6.9	7.0	7.0	6.8	7.1
Ortho PO_4 mg/L	8.6	-	-	-	-	-	-	-	-	7.2
Sol.Tot.P mg/L	9.6	10.2	9.6	9.2	9.8	9.0	9.6	8.8	24.0	8.8
Tot.P mg/L	11.0	206	194	160	86	91	96	94	208	-
Sol.Tot.KN mg/L	24.0	22.8	23.0	22.6	21.8	21.2	21.5	20.8	23.4	21.2
Tot.KN mg/L	25.0	248	230	202	118	125	128	127	256	-
SS mg/L	90	4280	4050	3290	1700	1780	1765	1770	4180	-
VSS mg/L	70	3095	2925	2460	1335	1430	1325	1330	3270	-
Sol.COD mg/L	220	-	-	-	-	-	-	-	-	55
Sol.MG mg/L	9.4	9.6	10.4	9.2	10.4	9.6	11.7	9.6	12.2	8.3
Sol.Ca mg/L	22.0	22.5	22.5	22.5	21.5	21.5	22.5	22.5	25.5	22.0
P/SS, Percent	-	4.6	4.5	4.6	4.5	4.6	4.9	4.8	4.4	-

Table A-6
(continued)

PROFILE ANALYTICAL RESULTS

4. Step Aeration Test System 12/16/69 - 10:00 a.m.

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
D.O. mg/L	-	0.2	0.2	1.2	0.3	5.2	7.2	7.8	-	2.0
pH	6.3	6.5	6.5	6.5	6.7	6.7	6.8	6.8	6.4	6.8
Sol.COD mg/L	180	75	65	70	60	60	60	60	100	55
Sol.TOC mg/L	75	35	30	30	35	30	30	30	45	30
Ortho PO_4 mg/L	9.8	30.7	21.4	12.1	11.5	5.1	3.6	-	41.5	4.4
Tot.P	10.6	192	190	188	130	130	125	128	510	6.8
NH_3-N mg/L	23.9	23.8	22.3	-	20.9	19.2	18.3	17.5	23.0	18.6
Sol.Tot.KN mg/L	26.0	-	22.4	21.0	21.0	19.4	19.0	18.2	23.5	21.2
Tot.KN mg/L	28.0	224	227	225	208	198	200	196	>600	-
SS mg/L	112	3540	3535	3450	2285	2240	2295	2325	9730	13
VSS mg/L	-	2550	2575	2500	1640	1650	1640	1685	7085	-
Sol.Mg mg/L	12.4	15.8	13.7	10.4	10.2	8.7	8.4	8.1	16.6	-
Sol.Ca mg/L	25.0	26.0	25.5	-	25.3	24.2	25.0	24.2	31.5	24.0
P/SS, Percent	-	4.6	4.8	5.1	5.2	5.5	5.4	5.3	5.0	-

5. High Flow Conventional Plug Flow Test System 12/10/69 - 10:00 a.m.

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
D.O. mg/L	-	0.1	0.1	0.3	1.4	4.7	5.7	6.4	-	0.5
pH	6.3	6.5	6.6	6.7	6.7	6.7	6.8	6.8	6.4	6.9
BOD_5mg/L	180	-	-	-	-	-	-	-	-	26
Sol.COD mg/L	220	60	65	65	60	50	50	50	130	55
Sol.TOC mg/L	-	35	35	30	30	30	30	25	45	30
Sol.Tot.P mg/L	10.8	30.0	29.4	18.0	8.4	4.2	3.6	-	>50	1.4
Tot.P mg/L	12.3	127	143	148	145	149	145	140	>05	-
NH_3-N mg/L	-	21.3	21.3	19.8	17.8	16.0	14.1	13.7	24.7	-
Sol.Tot.KN mg/L	25.0	22.4	22.0	20.2	18.4	16.8	15.8	15.0	25.4	15.7
Tot.KN mg/L	26.1	172	193	203	197	205	205	197	>600	-
NO_3-N mg/L	-	-	.25	-	-	-	.50	-	-	-
SS mg/L	110	1815	-	2115	-	2175	-	2200	11230	15
VSS mg/L	-	1445	-	1640	-	1680	-	1715	8810	-
Sol.Mg mg/L	-	17.6	17.3	14.8	-	10.2	10.0	10.4	28.4	-
Sol.Ca mg/L	-	25.0	25.0	25.0	23.5	25.0	23.5	25.0	31.0	-
P/SS, Percent	-	5.3	-	6.1	-	6.7	-	6.3	5.9	-

Table A-6
(continued)

PROFILE ANALYTICAL RESULTS

6. Normal Control System 12/3/69 - 4:00 p.m., MLSS = 1850 mg/L, P/SS = 5.4 percent

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
D.O. mg/L	-	0.1	0.1	0.3	1.0	3.6	4.6	5.2	-	1.2
pH	6.6	6.6	6.7	6.8	6.8	6.8	6.8	6.8	6.5	6.8
BOD_5mg/L	170	-	-	-	-	-	-	-	-	10
Sol.COD mg/L	215	75	70	55	50	40	35	30	90	45
Sol.TOC mg/L	110	55	50	40	35	30	30	25	55	35
Ortho PO_4 mg P/L	8.7	30.2	24.4	16.3	5.5	1.0	0.5	0.3	46.4	0.3
Sol.Tot.P mg P/L	9.7	33.0	27.0	18.8	6.2	1.4	0.8	0.7	>50	-
Tot.P mg P/L	-	98	97	98	98	100	98	102	520	-
Sol.Tot.KN mg/L	-	29.2	28.6	26.2	21.6	18.8	16.8	16.0	27.0	-
Tot.KN mg/L	36.0	150	156	154	152	156	148	152	516	-
Sol.Mg mg/L	-	17.6	16.8	14.0	11.0	8.8	8.0	7.6	17.0	-
Sol.Ca mg/L	-	26.5	27.8	26.5	25.0	30.0	24.0	25.0	30.0	-

7. Test System with Approach to Complete Mixing 12/3/69 - 4:00 p.m., MLSS = 1830 mg/L, P/SS = 5.4 percent

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
D.O. mg/L	-	0.1	0.2	0.2	1.2	4.0	5.5	5.8	-	2.0
pH	6.6	6.6	6.6	6.7	6.7	6.8	6.8	6.8	6.5	6.8
BOD_5 mg/L	170	-	-	-	-	-	-	-	-	7
Sol.COD mg/L	215	65	55	50	45	40	35	30	90	35
Sol.TOC mg/L	110	45	45	40	35	30	30	30	55	35
Ortho PO_4 mg P/L	8.7	30.4	24.7	18.0	6.0	1.0	0.8	0.5	44.6	0.4
Sol.Tot.P mg P/L	9.7	33.0	28.8	20.0	7.0	1.5	1.3	1.0	> 45	-
Tot.P mg P/L	-	96	102	100	98	100	102	96	480	-
Sol.Tot.KN mg/L	-	27.6	27.8	25.2	21.6	19.2	17.8	17.4	25.2	-
Tot.KN mg/L	36.0	136	162	160	152	154	152	146	500	-
Sol.Mg mg/L	-	15.8	15.8	13.4	9.8	7.8	7.2	7.6	-	-
Sol.Ca mg/L	-	26.5	26.5	25.5	25.5	25.0	27.5	26.5	-	-

8. Normal Control System 11/18/69 - 2:00 p.m.

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
D.O. mg/L	-	0.1	0.3	1.0	2.0	4.5	5.5	6.0	-	2.5
pH	6.3	-	-	-	-	-	-	-	-	7.0
BOD_5mg/L	160	-	-	-	-	-	-	-	-	8
Sol.COD mg/L	185	125	75	75	60	60	45	55	100	55
Sol.TOC mg/L	75	50	40	30	35	25	30	30	50	30
Ortho PO_4 mg P/L	6.8	25.1	-	6.7	1.5	-	0.1	0.1	15.0	0.1
Sol.Tot.P mg P/L	8.0	27.5	17.7	6.8	2.0	1.1	0.5	0.3	15.4	0.6
Tot.P mg P/L	10	110	108	106	108	114	106	120	-	C.8
NH_3N mg/L	30.0	28.0	24.6	20.6	18.8	18.0	16.8	17.0	24.0	17.5
Sol.Tot.KN mg/L	33.5	29.9	26.0	22.6	20.6	19.0	18.4	18.3	25.6	19.2
Tot.KN mg/L	34	144	146	134	136	148	132	156	-	-
SS mg/L	130	1840	1930	1920	1960	2000	2040	2050	8630	13
VSS mg/L	83	1480	1460	1520	1460	1500	1610	1610	6190	-
P/SS, Percent	-	4.5	4.7	5.1	5.4	5.6	5.2	5.8	-	-

Table A-6
(continued)

PROFILE ANALYTICAL RESULTS

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
9. Test System after Low D.O. Test 11/18/69 - 2:00 p.m.										
D.O. mg/L	-	0.1	0.2	0.4	1.0	2.2	3.7	4.8	-	1.0
pH	6.3	-	-	-	-	-	-	-	-	7.0
BOD$_5$ mg/L	160	-	-	-	-	-	-	-	-	11
Sol.COD mg/L	185	80	75	60	55	55	60	50	120	55
Sol.TOC mg/L	75	45	35	40	30	30	30	20	60	40
Ortho PO$_4$ mg P/L	6.8	-	16.6	7.6	0.1	0.1	0.1	0.1	15.7	1.6
Sol.Tot.P mg P/L	8.0	12.6	18.2	7.8	0.6	0.4	0.5	-	16.8	2.2
Tot.P mg P/L	10	90	88	88	86	80	82	86	-	2.8
NH$_3$N mg/L	30.0	23.4	23.8	21.4	19.2	16.8	16.6	17.6	25.2	18.8
Sol.Tot.KN mg/L	33.5	25.1	25.3	23.5	20.4	18.0	18.7	18.3	26.4	21.2
Tot.KN mg/L	34	130	131	130	132	122	128	134	>290	-
SS mg/L	130	1780	1830	1850	1890	1840	1880	1880	8370	10
VSS mg/L	83	1410	1530	1410	1530	1480	1470	1430	6350	-
P/SS, Percent		4.4	3.8	4.4	4.6	4.4	4.4	4.6	-	-
10. Normal Control System 10/23/69 - 2:00 p.m., MLSS = 1890,										
D.O. mg/L	-	0.1	-	-	4.0	-	-	6.7	-	1.8
pH	6.6	6.7	6.8	6.8	6.9	7.0	7.0	7.0	6.8	7.0
BOD$_5$ mg/L	150	-	-	-	-	-	-	-	-	9
Sol.COD mg/L	230	125	70	70	50	55	50	50	115	50
Sol.TOC mg/L	95	60	25	30	25	25	20	20	55	25
Ortho PO$_4$ mg P/L	8.5	23.5	8.0	1.5	1.0	0.8	0.5	0.5	19.7	
Sol.Tot.P mg P/L	-	>-	.6	-	1.0	-	<1.0	<1.0	> -	-
Tot.P mg P/L	12.0	66	67	62	73	77	75	77	175	1.5
NH$_3$N mg/L	33.9	30.8	26.6	23.7	19.9	18.4	16.3	16.2	20.7	15.4
Sol.Tot.KN mg/L	-	36.0	33.0	28.2	23.8	22.2	20.0	19.7	26.5	19.8
Tot.KN mg/L	-	132	130	130	140	140	141	143	-	-
NO$_2$+NO$_3$-N mg/L	<0.1	<0.1	0.1	0.1	0.1	0.1	0.1	0.1	<0.1	0.1
11. Test System During Low D.O. Test 10/23/69 - 2:00 p.m., MLSS = 1930,										
D.O. mg/L	-	0.1	-	-	0.1	-	-	0.3	-	0.1
pH	6.6	6.7	-	-	6.9	-	-	6.9	6.7	6.9
BOD$_5$ mg/L	150									38
Sol.COD mg/L	230	80	140	90	80	80	70	75	150	75
Sol.TOC mg/L	95	40	60	50	45	40	35	35	55	35
Ortho PO$_4$ mg P/L	8.5	8.9	12.7	11.0	10.0	9.3	10.8	11.8	25.5	10.8
Sol.Tot.P mg P/L	-	11.0	-	-	-	10.6	-	-	-	-
Tot.P mg P/L	12.0	46	41	36	39	40	45	45	130	11.0
NH$_3$N mg/L	33.9	31.3	30.9	28.9	26.2	22.5	20.7	20.3	24.8	19.8
Sol.Tot.KN mg/L	-	35.0	33.0	29.6	27.0	24.7	24.1	24.0	27.4	26.0
Tot.KN mg/L	-	140	130	126	125	126	145	143	284	-
NO$_2$+NO$_3$N mg/L	-	0.1	0.1	0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1

Table A-6
(continued)

PROFILE ANALYTICAL RESULTS

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
12. Normal Control System 9/17/69 - 10:30 a.m. SVI = 203										
D.O. mg/L	0.0	0.0	0.1	0.4	3.4	5.5	5.7	6.1	0.0	1.2
pH	6.5	6.7	6.8	6.9	6.9	6.9	7.0	7.0	6.7	7.2
*BOD_5 mg/L	247	151	48	26	17	17	19	-	-	-
Sol.COD mg/L	210	100	70	60	50	45	45	55	130	50
Sol.TOC mg/L	110	-	-	-	45	-	35	-	75	20
Ortho PO_4 mg P/L	8.7	21.7	11.5	2.8	0.3	0.1	0.1	0.1	21.7	0.1
Tot.P mg P/L	12.0	88	94	98	99	102	100	106	-	-
*ATP mg/L	0.03	1.36	1.90	2.05	2.16	2.46	2.50	2.46	9.21	-
NH_3N mg/L	12.0	12.0	11.5	8.0	7.0	5.5	5.0	4.5	8.5	4.5
Tot.KN mg/L	30	150	155	156	158	158	156	164	-	-
NO_2+NO_5N mg/L	0.04	0.23	0.12	0.14	0.24	1.39	2.46	2.49	2.00	3.28
*SS mg/L	175	2100	2350	2500	2400	2650	2575	2900	12050	-
*VSS mg/L	120	1475	1575	1700	1775	1750	1750	1950	8500	-
P/SS, Percent		3.2	3.5	3.8	4.1	3.9	3.9	3.7	-	-
13. Test System (After Low Flow Test) 9/17/69 - 10:30 a.m. SVI = 290										
D.O. mg/L	0.0	0.0	0.1	1.2	3.6	5.4	5.6	6.6	-	1.6
pH	6.5	6.8	6.9	6.9	6.9	6.9	7.0	7.0	6.6	7.2
*BOD_5 mg/L	241	120	60	28	17	14	13	11	-	-
Sol.COD mg/L	210	80	65	55	45	50	45	45	90	50
Sol.TOC mg/L	110	80	-	-	-	-	-	35	60	25
Ortho PO_4 mg P/L	8.7	10.2	1.3	0.6	0.3	0.2	0.3	0.2	20.6	0.3
*ATP mg/L	0.04	1.02	1.08	1.35	1.26	1.31	1.44	1.51	-	-
NH_3N mg/L	12.0	11.0	10.5	8.0	7.0	6.0	4.5	4.0	7.5	5.5
NO_2+NO_3N mg/L	0.04	0.14	0.09	0.14	0.77	1.07	2.15	3.27	0.20	3.34
*SS mg/L	190	2000	1725	1750	2000	1900	1900	2000	-	-
*VSS mg/L	110	1250	1250	1275	1350	1350	1300	1400	-	-
14. Normal Control System 8/27/69 - 2:00 p.m., MLSS = 2170, P/SS = 4.7, SVI = 150										
S.O. mg/L	-	0.1	-	-	6.0	-	-	4.9	-	1.3
pH	6.4	6.6	-	-	6.8	-	-	6.9	6.8	7.1
Sol.COD mg/L	130	70	50	50	60	70	70	50	-	50
Sol.TOC mg/L	110	70	50	55	50	60	65	50	-	45
Ortho PO_4 mg P/L	4.8	50.8	14.1	13.9	13.7	-	-	12.5	78	0.5
Sol.Tot.P mg P/L	6.0	-	15.0	15.0	13.8	13.2	-	13.0	-	0.5
Tot.P mg P/L	-	128	112	108	108	118	112	106	-	-
NH_3N mg/L	22.5	17.0	11.7	12.0	12.3	12.3	12.7	13.6	-	9.8
Tot.KN mg/L	32	120	100	90	95	84	92	88	-	12
NO_2+NO_3N mg/L	0.05	-	-	-	2.00	-	-	2.30	-	1.60

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* Designates analyses performed by Biospherics, Inc. under FWQA Contract No. 14-12-419.

Table A-6
(continued)

PROFILE ANALYTICAL RESULTS

15. Test System During High Solids Study 8/27/69 - 2:00 p.m., MLSS = 3200, P/SS = 3.1, SVI = 275

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	PE
D.O. mg/L	-	0.0	-	-	5.5	-	-	5.3	-	0.2
pH	6.4	6.6	-	-	6.8	-	-	6.9	6.7	7.1
Sol.COD mg/L	130	70	60	60	50	55	40	45	-	35
Sol.TOC mg/L	110	65	60	50	50	50	50	50	-	25
Ortho PO_4 mg P/L	4.8	75.0	52.5	26.1	19.0	16.8	19.0	16.3	-	1.1
Sol.Tot.P mg P/L	6.0	-	-	-	20.0	-	-	19.0	-	2.0
Tot.P mg P/L	-	116	124	96	-	118	-	-	-	-
NH_3N mg/L	22.5	17.5	15.7	14.0	13.3	12.0	12.2	11.8	-	8.8
Tot.KN mg/L	32	94	100	82	-	92	-	-	-	-
NO_2NO_3N mg/L	0.05	-	-	-	1.90	-	-	2.05		0.65

16. Normal Control System 7/25/69 - 5:00 p.m., MLSS = 2040 SVI = 87

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	PE
D.O. mg/L	-	0.0	-	-	0.3	-	-	3.5	-	0.8
pH	6.5	6.8	-	-	6.8	-	-	6.9	6.8	7.2
Sol.COD mg/L	480	240	180	150	150	130	125	125		130
Sol.TOC mg/L	215	133	108	95	95	95	78	83	-	87
Ortho PO_4 mg P/L	6.2	19.5	21.5	16.5	9.8	1.5	0.5	0.5		0.5
NH_3N mg/L	17.2	19.8	20.0	17.5	17.0	14.5	14.0	13.5		11.7
Tot.KN mg/L	28	30	23	20	16	16	15	-		13

17. Test System During Low D.O. Study 7/25/69 - 5:00 p.m., MLSS = 1930 SVI = 68

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	PE
D.O. mg/L	-	0.0	-	-	0.1	-	-	0.6	-	-
pH	6.5	6.8	-	-	6.9	-	-	6.9	6.9	7.0
Sol.COD mg/L	480	360	246	205	180	185	180	185	-	200
Sol.TOC mg/L	215	195	145	110	115	110	110	115	-	-
Ortho PO_4 mg P/L	6.2	10.0	6.5	5.0	3.0	4.5	5.5	5.2	-	5.0
NH_3N mg/L	17.2	18.0	17.3	15.5	16.0	12.5	13.6	11.5	-	-
Tot.KN mg/L	28	22	21	18	17	16	16	15	-	17

18. Normal Control System 6/12/69 - 4:00 p.m.

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	PE
D.O. mg/L	-	0.2	-	-	0.1	-	2.5	4.9	-	-
Ortho PO_4 mg P/L	7.7	>25	>25	24.5	14.1	11.8	2.5	-	-	0.3
Sol.Tot.P mg P/L	12.7	41.7	38.1	27.6	21.0	-	-	0.5	-	0.4
NH_3N mg/L	17.0	21.3	19.2	20.0	16.2	15.9	13.1	12.5	-	8.0
Sol.Tot.KN mg/L	37	34	32	30	28	28	21	19	-	14

Table A-6
(continued)

PROFILE ANALYTICAL RESULTS

19. Test System at Normal Operation 6/12/69 4:00 PM

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
D.O. mg/L	-	0.1	-	-	0.2	-	1.0	1.9	-	-
Ortho PO_4 mg P/L	7.7	>25	-	>25	22.8	20.4	5.4	2.1	-	0.3
Sol.Tot.P mg P/L	12.7	40	38	36	32	-	7.2	3.2	-	0.4
NH_3N mg/L	17.0	20.6	23.4	21.0	19.4	17.3	12.0	-	-	8.0
Sol.Tot.KN mg/L	37	37	36	33	30	29	22	18	-	16

20. Normal Control System 5/20/69 - 10:00 a.m.

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
D.O. mg/L	-	0.1	0.0	0.0	0.1	0.2	3.9	6.0	-	-
D.O. Uptake mg/L/hr	-	74	134	59	60	17	20	23	-	-
pH	-	6.6	6.8	6.9	6.9	7.0	6.9	7.0	-	-
Sol.TOC mg/L	-	67	50	46	41	45	36	31	-	-
Ortho PO_4 mg/L	-	17.5	16.5	14.7	6.7	4.0	0.2	0.2	-	-
NH_3N mg/L	-	15.2	14.2	13.4	12.5	11.9	10.5	10.2	-	-
Alkalinity mg/L (to pH = 4.5)	-	225	188	185	197	178	185	170	-	-

21. Test System at Normal Operation 5/20/69 - 1:00 p.m.

	PE	AT-1	AT-2	AT-3	AT-4	AT-5	AT-6	AT-7	RS	SE
D.O. mg/L	-	0.0	0.0	0.0	0.1	0.2	2.4	5.0	-	-
D.O. Uptake mg/L/hr	-	64	156	70	63	60	30	22	-	-
pH	-	6.8	7.0	7.1	7.1	7.2	7.3	7.3	-	-
Sol.COD mg/L	-	130	85	65	45	50	40	45	-	-
Ortho PO_4 mg P/L	-	17.5	15.5	9.5	4.5	6.3	0.3	0.2	-	-
Tot.P mg P/L	-	77	75	75	74	73	76	73	-	-
NH_3N mg/L	-	17.8	17.5	15.7	15.0	14.1	11.6	10.2	-	-
Alkalinity mg/L (to pH = 4.5)	-	212	218	208	202	205	180	173	-	-

Table A-7

Total Inorganic Carbon Results

Date	Type Sample	Sample Points, mgC/L						
		PE	AT-1	AT-2	RS-1	RS-2	SE-1	SE-2
6/19/69	Composite	32	40	40	-	-	38	43
7/7/69	Composite	33	45	45	50	53	32	33
7/23/69	Composite	36	32	48	59	62	30	31
7/30/69	Composite	38	45	52	50	58	38	36
8/4/69	Grab	28	35	34	35	35	35	32
8/11/69	Grab	28	35	34	35	34	34	32
8/18/69	Grab	26	28	32	31	32	32	40
8/25/69	Grab	31	36	37	34	33	31	32
9/8/69	Grab	33	33	32	33	25	27	20
9/15/69	Grab	35	42	42	35	37	37	37
9/22/69	Grab	30	39	39	29	30	29	29
9/29/69	Grab	31	33	34	39	36	33	30
10/10/69	Grab	37	40	40	53	42	41	41
10/21/69	Grab	39	38	39	34	40	40	41
11/3/69	Grab	38	40	40	41	39	41	41
11/25/69	Grab	34	43	41	51	42	44	40
12/24/69	Grab	30	35	36	32	39	30	30
Average		33	37	39	40	40	35	35

Note: Composite samples were stored daily collection and the results are questionable. Grab samples were analyzed within one hour of collection time, eliminating changes due to storage

Table A-8

Baltimore Phosphate Removal Study

Characteristics of Wastewaters From Sludge Handling Operations

Sample Date	Time	Type	Total mgP/L	SS mg/L	VSS mg/L	COD mg/L	Total Kjeldahl Nitrogen mg/L	Magnesium mg/L	Calcium mg/L	Iron mg/L
Elutriation Wastewater										
2/10/70	4 p.m.	Total	85	2840	1890	-	>210	24.0	100	59
		Soluble	57	-	-	760	195	17.0	37	0.8
2/11/70	11a.m.	Total	64	930	800	-	>210	22.0	56	23
		Soluble	57	-	-	740	205	16.6	35	1.5
2/11/70	4 p.m.	Total	60	800	700	-	205	18.6	56	24
		Soluble	53	-	-	760	188	16.6	20	1.2
2/12/70	4 p.m.	Total	60	950	740	-	196	21.0	56	21
		Soluble	51	-	-	730	190	18.0	41	1.3
Vacuum Filter Filtrate Wastewater										
2/10/70	4 p.m.	Total	24	820	550	-	58	16.6	58	20
		Soluble	16	-	-	165	42	15.0	20	0.5
2/11/70	11a.m.	Total	24	320	290	-	58	16.2	51	12
		Soluble	19	-	-	175	50	15.6	42	0.7
2/11/70	4 p.m.	Total	26	450	380	-	61	16.6	51	10
		Soluble	21	-	-	165	52	16.6	45	0.7
2/12/70	4 p.m.	Total	26	520	420	-	63	18.0	58	12
		Soluble	19	-	-	175	52	16.1	45	1.0

Note: For normal operation of 2 vacuum filters the Elutriation wastewater averages 1,500-1,800 gpm, and the Filtrate wastewater averages 600-800 gpm. During average operation, polymer was added for conditioning, and the vacuum filter product was about 20% solids cake from a 3-4% solids elutriated sludge stream.

Table A-9

Baltimore Phosphate Removal Study
Air Supply Rates for
Rapid Dissolved Oxygen Variation Test

Date	Time	System No. 2		System No. 1 Air Supply SCFM	Number of Blower Operating
		Air Supply SCFM	Change		
11/10/69	12:00 Noon	8,800		7,800	1
11/11/69	3:15 p.m.	6,000	Down	10,700	1
	5:45 p.m.	4,400	Down	12,900	1
	11:30 p.m.	8,800	Up	7,900	1
11/12/69	8:30 a.m.	14,800	Up	13,000	2
	11:00 a.m.	8,700	Down	7,800	1
	3:30 p.m.	4,400	Down	12,500	1
11/13/69	12:15 a.m.	7,700	Up	9,000	1
	10:45 p.m.	8,800	Up	7,800	1
	5:00 p.m.	4,300	Down	12,800	1
	11:00 p.m.	7,800	Up	8,800	1
11/14/69	7:00 a.m.	12,500	Up	14,100	2
	6:15 p.m.	7,400	Down	9,100	1
	7:00 p.m.	4,100	Down	13,100	1
11/15/69	6:00 a.m.	8,000	Up	9,300	1
	9:15 a.m.	9,500	Up	7,500	1
	6:00 p.m.	9,100	Down	8,300	1
11/16/69	5:30 p.m.	5,000	Down	12,600	1
11/17/69	7:30 a.m.	9,100	Up	8,200	1
11/18/69	1:15 a.m.	5,100	Down	12,600	1
	8:45 a.m.	9,000	Up	8,300	1

Table A-10

Baltimore Phosphate Removal Study
Summary of Oxidation Reduction Potential Results

Date	ORP at Outlet From Test Aeration Tank	
	Average Millivolts	Range Millivolts
11/14/69	370	200 - 490
11/15/69	350	130 - 510
11/16/69	505	460 - 530
11/17/69	440	265 - 520
11/18/69	435	230 - 515
11/24/69	565	560 - 570
11/25/69	565	560 - 570
11/26/69	570	565 - 575
11/27/69	565	560 - 570
11/28/70	545	540 - 560
11/29/70	550	545 - 555
12/2/69	505	465 - 530
12/3/69	530	515 - 545
12/4/69	535	525 - 545
12/8/69	540	515 - 545
12/9/69	535	495 - 550
12/10/69	535	525 - 545
12/11/69	540	495 - 550
12/12/69	540	535 - 545
12/13/69	545	545
12/14/69	505	475 - 545
12/15/69	510	495 - 520
12/16/69	525	515 - 530
12/17/69	515	505 - 530
12/18/69	505	495 - 515
12/19/69	505	500 - 510
12/20/69	505	500 - 510
12/21/69	505	500 - 510
12/22/69	505	500 - 510

Note: The above Eh values for ORP were determined by correcting the Ag, AgCl half-call results by +197 mV to the instrument reading.

Table A-11

Baltimore Phosphate Removal Study

Laboratory Batch Study on Effect of Suspended Solids on Phosphorus Removal

									Centrifugal (Soluble)							
Time minutes	pH	Dissolved Oxygen mg/L	D.O. Uptake mg/L/m	Total Suspended Solids mg/L	Volatile Suspended Solids mg/L	Total Phosphorus mg/P/L	Total Kjeldahl Nitrogen mg/N/L	Total ATP mg/L	Total Phosphorus mg/P/L	Ortho Phosphate mg/P/L	BOD mg L	COD mg/L	Total Carbon mg/L	Total Kheldahl Nitrogen mg/L	Ammonia Nitrogen mg/L	Nitrate and Nitrate Nitrogen mg/L
Test Number 1																
0[1]	---	---	---	-----	-----	---	---	----	15.2	13.0	117	160	70	27.5	20.1	----
2	7.1	--	---	3,140	2,410	102	142	----	32.0	29.9	50	70	--	20.0	----	0.10
10	---	1.1	120	-----	-----	---	---	----	22.1	20.0	---	68	30	18.4	12.5	0.10
20	---	---	---	-----	-----	---	---	----	10.8	8.7	---	66	30	16.0	11.7	0.10
30	7.5	---	60	2,980	2,340	---	---	----	2.5	1.9	34	62	30	15.0	10.4	0.10
40	---	6.4	---	-----	-----	---	---	----	0.4	0.3	---	59	30	13.8	9.8	0.20
60	7.5	---	54	3,160	2,370	---	---	----	0.4	0.2	---	56	25	13.2	9.4	0.40
90	---	---	---	-----	-----	---	---	----	0.3	0.1	34	54	20	11.6	8.7	0.70
120	7.8	---	42	-----	-----	104	135	----	0.4	0.1	---	51	20	11.0	8.2	1.00
540	7.5	6.4	20	2,970	2,260	---	---	----	0.5	0.2	---	50	15	8.6	6.3	4.60
1200	7.9	---	---	-----	-----	---	---	----	1.4	1.4	---	62	--	7.4	5.0	6.00
Test Number 2																
0[1]	---	---	---	-----	-----	---	---	----	10.7	9.3	116	156	69	22.7	18.5	----
2	7.3	---	---	2,050	1,650	62	82	1.44	14.6	14.5	52	70	--	17.4	----	.05
10	---	3.2	102	-----	-----	---	---	1.75	9.4	9.3	---	67	35	15.2	12.0	.05
20	---	---	---	-----	-----	---	---	----	4.4	3.5	---	67	30	14.8	11.4	.08
30	7.7	---	54	1,840	1,450	---	---	1.81	1.2	1.0	31	65	31	14.2	11.4	.20
40	---	6.4	---	-----	-----	---	---	----	0.7	0.5	---	62	30	13.6	11.1	.22
60	7.8	---	33	2,100	1,660	72	92	1.99	0.3	0.2	---	56	25	12.8	9.8	.32
90	---	---	---	-----	-----	---	---	2.16	0.3	0.2	33	54	20	12.2	9.2	.44
120	8.0	---	18	-----	-----	64	84	----	----	----	---	58	--	----	----	.16
180	7.8	---	17	1,800	1,410	---	---	----	0.3	0.2	---	50	15	11.4	7.9	.98
540	7.8	6.5	12	-----	-----	62	76	----	0.4	0.2	---	48	10	9.2	7.0	2.80
1200	8.3	---	---	-----	-----	---	---	----	1.3	1.2	---	48	10	7.4	7.2	5.50
Test Number 3																
0[1]	---	---	---	-----	-----	---	---	----	7.7	6.6	115	155	69	21.6	17.2	----
2	7.4	---	---	1,250	870	---	52	0.84	8.3	8.2	54	---	40	17.2	11.7	----
10	---	2.0	40	-----	-----	---	---	0.86	7.7	7.5	---	68	40	16.4	12.5	----
20	---	---	---	-----	-----	---	---	----	4.9	4.7	---	62	--	16.2	11.5	----
30	7.8	6.3	30	1,000	870	---	---	1.01	3.0	2.8	33	57	30	15.8	12.3	----
40	---	---	---	-----	-----	---	---	----	2.2	2.0	---	55	30	15.2	11.7	----
60	7.8	---	25	1,030	840	40	52	1.08	1.2	1.1	---	50	30	14.8	11.1	----
90	---	---	---	-----	-----	---	---	1.07	0.5	0.5	36	55	30	14.2	10.6	----
120	8.0	---	18	-----	-----	40	55	----	0.3	0.3	---	50	25	12.0	8.8	----
180	---	---	15	1,010	760	---	---	----	0.4	0.2	---	48	25	12.0	9.2	----
540	8.0	6.0	---	960	700	38	48	----	0.8	0.4	---	50	20	11.0	8.3	----
1200	8.5	---	---	-----	-----	---	---	----	1.1	0.9	---	46	10	9.0	7.2	----

Note: [1]Initial Computed Values Include Some Effects of Primary Effluent Suspended Solids.

Table A-12

Baltimore Phosphate Removal Study

Laboratory Data For Tests To Maintain Phosphorus Removal

Total Phosphorus Removal, percent

Test	1	2	3	4	5	6
Date	10/7/69	12/3/69	10/28/69	11/6/69	11/25/69	10/23/69
Full-Scale Removal	86	90	94	95	89	89
Time From Start-up						
2				38	82	
4				62	83	83
6				81	78	84
8	26			86	68	84
10		50		84	63	74
12			80	84	66	81
14				81	66	79
16	67			82	68	72
18				77	-	68
20				68	51	58
22				65	54	51
24	95	63	77	56	47	48
26				46	47	56
28				38	42	60
30				34	35	38
32	88			26	34	15
34		89		19	32	23
36			81	33	30	
38				28	27	
40				26	23	
42	78				17	
44					7	
46		84				
48			83		11	
52	70				17	
56					19	
58		82				
62	90		81			
70		84			16	
74			77		10	
80		90				

Note:
Test 1 - Plug Flow Without Sludge Wasting
Test 2 - Plug Flow With 2%/Day Sludge Wasting
Test 3 - Plug Flow With 6 hr. Settling
Test 4 - Complete Mixing - 6 hr Aeration, 2 hr. Settling
Test 5 - Step Aeration - Feed At Beginning, 1/3 and 2/3 points of A.T.
Test 6 - Contact Stabilization - 2 hr Contact, 4 hr Stabilization

Table A-13

Baltimore Phosphate Removal Study Operation

Observation of Metal Variations With Time

Date and Time		Total P MgP/L	Orthro P mg/L	COD mg/L	Metal Ions Mg++ mg/L	Ca++ mg/L	Fe+++ mg/L
2/9	11:30 p.m.		9.2/4.6	270/60	9.9/9.4	29.0	-
2/10	5:00 p.m.		5.2/0.6	155/50	11.7/8.4	-	-
2/11	4:00 p.m.		6.2/1.8	210/65	12.0/10.8	37.4	-
	6:00 p.m.		6.6/1.6	240/55	11.7/11.4	34.4	.86
	10:00 p.m.		6.8/2.0	450/65	11.4/11.1	32.0	1.05
2/12	2:00 a.m.		6.5/3.4	190/70	10.7/11.0	31.0	1.55
	6:00 a.m.		4.8/8.6	370/65	10.8/11.0	31.0	1.25
	10:00 a.m.		3.8/9.2	160/65	12.4/11.8	36.4	.74
	2:00 p.m.		5.7/7.5	370/80	12.4/12.2	35.0	.46
	6:00 p.m.		7.2/6.8	285/65	11.7/12.4	31.4	.70
	10:00 p.m.	13.8/6.6	6.9/6.2	490/70	11.5/12.4	31.4	.46
2/13	2:00 p.m.		6.5/6.1	355/70	11.2/11.7	31.4	1.13
	6:00 p.m.		5.8/2.0	270/85	11.2/10.0	31.0	.77
	10.00 a.m.	8.4/3.5	5.2/3.4	300/70	11.9/9.8	32.0	.42/≤.1
2/26	9:00 p.m.		7.4/.3	405/75	9.2/8.4	26.6/26.6	2.6
	11:30 p.m.		7.7/.3	420/70	9.4/8.4	26.0/28.0	1.92
2/27	9:00 a.m.		6.4/.8	295/75	10.6/86	26.6/26.0	1.28
	3:00 p.m.		7.5/.3	365/65	13.0/7.8	26.6/26.6	1.52
	6:00 p.m.		8.9/.2	410/70	13.2/8.8	27.0/26.6	1.62
	11:30 p.m.	16.5/0.5	8.4/.3	450/80	12.0/9.4	26.6/26.6	1.82
2/28	8:30 a.m.	13.5/1.0	7.4/.9	325/75	13.4/9.7	30.0/26.6	1.38
	5:00 p.m.	19.5/1.5	8.6/0.2	350/75	9.6/9.4	25.0/27.0	1.94
	9:00 p.m.		8.8/0.2	470/60			
	10:30 p.m.	20.0/0.8	8.6/0.5	435/85	9.8/8.8	30.0/30.0	1.52/.58
3/1	9:00 a.m.	10.2/1.7	6.8/1.5	265/85	9.8/9.2	26.0/26.0	.76
	1:00 p.m.	7.5/0.8	6.0/.7	285/85	10.4/7.2	27.0/26.0	.78

Note: The data in this table refer to concentrations in the Primary Effluent and the Secondary Effluent from System No. 1 (PE/SE 1). Where only one value is shown it refers to Primary Effluent.

Table A-14

Phosphorus Removal Accountability by Theoretical Metal and Biological Requirements

System No. 1 - Control - Weekly Average

Date of Week	System Total Phosphorus Removal		Minimum Biological Requirement (P/BOD=0.01)		POSSIBLE PHOSPHORUS REMOVAL BY METALS												Accountability Total	Difference
					Calcium (P/Ca=0.52)		Magnesium (P/Mg=0.86)		Iron (P/Fe=0.55)		Aluminum (R/Al=1.14)		Copper (P/Cu=0.48)		Zinc (P/Zn=0.47)			
			BOD$_5$	P	Ca	P	Mg	P	Fe	P	Al	P	Cu	P	Zn	P	P	P
	percent	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
7-14	37	4.6	175	1.8	5.6	2.9	2.9	2.5	2.6	1.4	1.6	1.8	0.2	0.10	0.5	0.20	10.7	+6.1
7-22	83	9.7	114	1.1	(1.7)	0.9	.3	.3	1.4	0.8	1.3	1.5	0.2	0.10	1.1	.50	5.2	-4.5
7-29	52	6.0	167	1.7	8	4.2	1.5	1.3	1.4	0.8	2.0	2.3	0.1	0.05	0.4	0.20	10.5	+4.5
8-4	69	7.0	143	1.4	2	1.0	1.0	.9	1.7	0.9	2.5	2.9	0.2	0.10	0.5	.20	7.4	+0.4
8-11	90	8.5	160	1.6	.9	0.5	5.3	4.6	1.9	1.0	1.8	2.0	0.2	0.10	0.4	.20	10.0	+1.5
8-18	81	7.8	101	1.0	1.0	0.5	1.8	1.5	0.9	0.5	1.5	1.7	0.1	0.05	0.3	.10	5.3	-2.5
8-25	88	6.8	146	1.5	5.5	2.9	1.2	1.0	1.7	0.9	1.1	1.3	0.6	0.30	0.5	.20	8.1	+2.3
9-2	82	7.5	120	1.2	(1.7)	0.9	1.5	1.3	3.8	2.1	1.6	1.8	0.3	0.10	0.7	.30	7.6	+0.1
9-8	74	9.7	138	1.4	(1.7)	0.9	0.7	0.6	2.1	1.2	2.1	2.4	0.3	0.10	0.8	.40	7.0	-2.7
9-15	87	10.4	221	2.2	2.5	1.3	1.2	1.0	0.8	0.4	1.1	1.3	0.2	0.10	0.4	.20	6.5	-3.9
9-22	81	8.7	174	1.7	(1.7)	0.9	3.1	2.7	6.1	3.3	1.1	1.3	0.3	0.10	0.7	.30	10.3	+1.6
9-29	73	9.6	80	0.8	4.5	2.3	2.5	2.2	4.3	2.4	3.3	3.8	0.5	0.20	1.4	.70	12.4	+2.8
10-7	74	8.3	137	1.4	3.0	1.6	4.4	3.8	3.1	1.7	1.1	1.3	0.8	0.40	0.8	.40	10.7	+2.4
10-14	91	9.2	174	1.7	2.5	1.3	5.5	4.7	3.6	2.0	1.4	1.6	0.3	0.10	1.8	.80	12.2	+3.0
10-20	47	5.6	106	1.1	1.7	0.9	2.0	1.7	1.5	.8	.7	0.8	0.3	0.10	0.3	.10	5.5	-0.1
10-28	92	12.4	179	1.8	6.7	3.5	2.2	1.9	1.9	1.0	0.3	0.3	0.1	0.05	0.9	.40	8.9	-3.5
11-3	94	10.2	153	1.5	1.7	0.9	4.2	3.6	1.0	0.6	1.6	1.8	0.3	0.10	0.7	.30	8.8	-1.4
11-10	93	10.6	174	1.7	1.7	0.9	5.9	5.1	0.4	0.2	1.6	1.8	0.3	0.10	0.7	.30	10.1	-0.5
11-17	87	10.5	182	1.8	1.7	0.9	4.3	3.7	1.8	1.0	1.6	1.8	0.3	0.10	0.7	.30	8.6	-1.9
11-24	91	13.1	149	1.5	2.5	1.3	6.2	5.3	2.4	1.3	.5	0.6	0.3	0.10	0.7	.30	10.4	-2.7
12-1	83	9.2	165	1.7	(1.7)	0.9	7.0	6.0	3.6	2.0	1.0	1.1	0.3	0.10	0.7	.30	12.1	+2.9
Average	79	8.8		1.5		1.4		2.7		1.3		1.7		0.1		.3	9.0	+0.2

Table A-14
(continued)

Phosphorus Removal Accountability by Theoretical Metal and Biological Requirements

System No. 2 - Test - Weekly Average

Date of Week	System Total Phosphorus Removal		Minimum Biological Requirement (P/BOD=0.01)		POSSIBLE PHOSPHORUS REMOVAL BY METALS										Zinc (P/Zn=0.47)		Accountability Total	Difference
					Calcium (P/Ca=0.52)		Magnesium (P/Mg=0.86)		Iron (P/Fe=0.55)		Aluminum (R/Al=1.14)		Copper (P/Cu=0.48)					
	Removal percent	mg/L	BOD_5 mg/L	P mg/L	Ca mg/L	P mg/L	Mg mg/L	P mg/L	Fe mg/L	P mg/L	Al mg/L	P mg/L	Cu mg/L	P mg/L	Zn mg/L	P mg/L	P mg/L	P mg/L
7-14	13	1.6	172	1.7	6.6	3.4	2.2	1.9	2.3	1.3	1.6	1.8	.2	0.1	.5	0.2	10.4	+8.8
7-22	21	2.5	99	1.0	(2.1)	1.1	.3	0.3	0.4	0.2	1.0	1.1	0.2	0.1	1.0	.5	4.5	+1.8
7-29	24	2.8	162	1.6	5.0	2.6	0.8	0.7	1.7	0.9	2.0	2.3	0.2	0.1	0.4	0.2	8.4	+5.6
8-4	67	6.8	141	1.4	5.0	2.6	2.8	2.4	1.8	1.0	0	0	0.2	0.1	0.4	0.2	7.7	+0.9
8-11	75	7.1	164	1.6	.5	0.3	4.8	4.1	2.1	1.2	1.0	1.1	0.2	0.1	0.5	0.2	8.6	+1.5
8-18	72	6.9	103	1.0	1.0	0.5	2.5	2.2	1.0	1.5	0	0	0.1	0.05	0.4	0.2	4.5	-2.4
8-25	82	6.3	141	1.4	4.0	2.1	1.8	1.5	2.0	1.1	0.9	1.0	0.6	.3	0.5	0.2	7.6	+1.3
9-2	85	7.8	114	1.1	(2.1)	1.1	0.3	0.3	3.5	1.9	1.6	1.8	0.3	.1	0.6	0.3	6.6	-1.2
9-8	88	11.6	153	1.5	3.6	1.9	1.0	0.9	3.0	1.7	2.4	2.7	0.3	.1	1.0	0.5	9.3	-2.3
9-15	83	9.9	229	2.3	.8	0.4	1.8	1.5	2.7	1.5	2.1	2.4	0.2	.1	0.7	0.3	8.5	-1.4
9-22	89	9.5	184	1.8	(2.1)	1.1	2.4	2.1	6.1	3.4	1.1	1.3	0.3	.1	0.8	0.4	10.2	+0.7
9-29	91	11.8	91	0.9	3.5	1.8	2.8	2.4	4.3	2.4	3.3	3.8	0.5	.2	1.5	0.7	12.2	+0.4
10-7	89	9.9	144	1.4	(2.1)	1.1	3.6	3.1	3.1	1.7	1.1	1.3	0.8	.4	0.8	0.4	9.4	-0.5
10-14	86	8.7	171	1.7	4.0	2.1	5.0	4.3	5.9	3.2	1.4	1.6	0.3	.1	1.8	0.8	13.8	+5.1
10-20	18	2.2	97	1.0	2.1	1.1	0.2	0.2	2.4	1.3	0.7	0.8	0.3	.1	0.6	0.3	4.8	+2.6
10-28	39	5.3	168	1.7	6.3	3.3	(2.3)	2.0	0.5	0.3	0.3	0.3	0.1	.05	0.8	0.4	8.1	+2.8
11-3	94	10.2	154	1.5	2.1	1.1	3.5	3.0	0.6	0.3	1.6	1.8	0.3	.1	0.8	0.4	8.2	-2.0
11-10	49	5.6	173	1.7	2.1	1.1	4.6	4.0	0.7	0.4	1.6	1.8	0.3	.1	0.8	0.4	9.5	+3.9
11-17	61	7.3	183	1.8	2.1	1.1	2.7	2.3	2.4	1.3	1.6	1.8	0.3	.1	0.8	0.4	8.8	+1.5
11-24	77	11.1	149	1.5	3.0	1.6	5.1	4.4	2.4	1.3	0.5	0.6	0.3	.1	0.8	0.4	9.9	-1.2
12-1	84	9.1	165	1.7	1.7	0.9	9.8	8.4	3.6	2.0	1.0	1.1	0.3	.1	0.8	0.4	14.6	+5.5
12-6	88	9.3	161	1.6	0.5	0.3	2.6	2.2	2.2	1.2	1.0	1.1	0.3	.1	0.8	0.4	6.9	-2.4
12-11	78	8.4	130	1.3	1.0	0.5	1.5	1.3	4.7	2.6	2.5	2.9	0.3	.1	0.8	0.4	9.1	+0.7
12-18	32	3.8	193	1.9	(2.1)	1.1	(2.3)	2.0	2.5	1.4	0.4	0.5	0.3	.1	0.8	0.4	7.4	+3.6
Average	66	7.3		1.5		1.4		2.4		1.4		1.5		.1		0.4	8.8	+1.4

Table A - 15

Baltimore Phosphate Removal Study

BOD of Wastewater Samples
Normal and Nitrification - Inhibited Values

Date	Sample Source*	Normal BOD		Nitrification Inhibited With Thiourea		Avg	Initial			Observed Increase In NO_3-N Over 20 Days		Computed Oxygen Need For Nitrate Formation	Difference Between Normal and Nitrated BOD_{20} Value
		BOD_5	BOD_{20}	BOD_5	BOD_{20}	BOD_5	COD (Auto)	TOC	NH_3-N	Normal	Inhibited		
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg^{O}/L	mg^{O}/L
11/12/69	SE1	7	80	6	21	7	55	35	13.6	14	1	61	59
	SE2	9	98	12	29	11	60	40	14.3	15	<1	68	69
	PE	195	445	205	260	200	270	130	23.2	41	<6	178	185
11/11/69	SE1	6	88	7	20	7	55	40	18.4	22	<1	100	68
	SE2	5	86	5	16	5	50	40	18.2	22	<1	100	70
	PE	160	410	160	245	160	295	145	29.5	40	<6	173	165
11/10/69	SE1	4	87	4	12	4	50	40	18.0	24	1	107	75
	SE2	2	82	2	11	2	50	40	17.2	21	1	93	71
	PE	150	415	155	235	155	320	160	29.4	60	<6	265	180
9/11/69	SE1	22	65	18	40	20	60	-	7.6	15	2	61	25
	SE2	27	80	25	44	26	55	-	3.0	-	-	-	36
	PE	190	410	195	270	145	305	-	20.5	43	<3	194	140
9/10/69	SE1	29	92	22	40	26	70	30	9.5	21	<1	95	52
	PE	170	380	165	280	170	275	90	16.0	57	<3	260	100

*SE1 is Secondary Effluent from System No. 1
SE2 is Secondary Effluent from System No. 2
PE is Primary Effluent

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APPENDIX B

INSTRUMENTATION SYSTEM FOR SIMULTANEOUS MONITORING FOR MULTIPLE CHEMICAL PARAMETERS AT THE BALTIMORE ACTIVATED SLUDGE PLANT

Introduction

The application of extensive continuous monitoring instrumentation to the activated sludge biological treatment process for wastewater is very limited at this time. Conservative activated sludge design has been the traditional approach to handle a variable inlet feed stream to the process and yet accomplish an acceptable range of quality of treated effluent. However, the current demands for consistently high effluent quality and for optimized process performance are much greater. To meet these demands, the new application of monitoring instrumentation is needed to provide immediate information readout so that timely, appropriate process changes can be made to maintain optimum process performance.

The following information describes an extensive instrumentation system installed at the activated sludge portion of the Baltimore, Maryland Back River Wastewater Treatment Plant which was operated from June to December 1969. The automatic sampling and analytical instrumentation will first be described, and then typical recorded data output will be presented. Finally, the problems associated with the sampling and analytical instrumentation and the application of such systems for permanent installation at activated sludge plants will be discussed.

Description of Monitoring System

The overall monitoring system was designed for continuous operation with automatic hourly retrieval at as many as eleven sample points located at various parts of the treatment plant. The parameters measured were: pH, turbidity, total dissolved carbon, dissolved COD, nitrite-nitrate, ammonia, orthophosphate, and, on a less frequent basis, total phosphate and total Kjeldahl nitrogen. Other parameters measured by manual methods were: suspended solids, BOD, and specific metal ions. These samples for manual determination were collected and handled in a specially-designed, completely-automated and refrigerated sampling system. The sensors, automated wet-chemical procedures, and sample collection operations were coupled in a completely synchronized operation.

The eleven sampling points (specific locations are shown in Figure B-1) were:

Two in the effluent from the two secondary clarifiers
(Sample Points 1 and 2)

One at the influent to the aeration system (Sample Point 3).

Six in the aeration tanks, sampling the beginning (Sample Points 4 and 5), the middle (Sample Points 6 and 7), and the end (Sample Points 8 and 9) of each of the two aeration Tanks.

Two in the return sludge flow in the control building (Sample Points 10 and 11).

The activated sludge plant was modified so that it consisted of two separate 10 mgd treatment facilities, to provide one system that could be operated on a normal operating basis, while test conditions could be imposed on the second system. The analytical systems were installed in the central control building, with the most distant sampling point being approximately 400 feet away. One inch diameter polyethylene tubing was used to transport the wastewater from the sampling point to the analytical complex. Submersible 1/5 HP pumps mounted approximately two feet below the surface at each sample point and supported on a metal bracket provided a 4-6 gpm continuous-flow sample stream. Three-way valves were mounted on each of the sample transmission lines so that the system could be backwashed with a hypochlorite solution on a weekly basis.

At each of the 6 sampling points located in the aeration tanks, dissolved oxygen sensing probes were mounted on the submersible sampling pumps. Two additional oxygen sensing probes were mounted in the supernatant liquid, approximately one foot under the surface in each of the two final clarifiers. The dissolved oxygen probes were Weston and Stack units consisting of a Model A-40 dissolved oxygen monitoring probe and a Model A-25 cleaner-agitator device. The electrical signals from these probes were transmitted to a Weston and Stack Model 3000 analyzer and switching unit and then to a Leeds and Northrup Speed-O-Mac, Model H, multi-point recorder for data readout.

A flow diagram of the entire sampling switching and analysis system is presented in Figure B-2. All sample lines and fittings from the submersible sampling pumps located at individual sampling points to the main overflows in the sampler building were sized at one-inch diameter so that the 4-6 gpm sample stream flow could be maintained. Sample stream flow through the remainder of the system beyond that point was reduced to approximately 1/3 gpm due to the use of 1/4 in. diameter Solenoid valves and reduction of other lines and fittings to 1/2 in. diameter. The sample line flushing system that was used on a once-a-week basis consisted of a 200-gallon polyethylene tank and a 1/20-HP pump that provided a flushing flow of 8 to 10 gpm through the negative head system. The in-line "Y" strainers were flushed out on a daily basis.

The sample stream switching and sample collection activities of the system were provided by a TAFI (Technical Associates For Industry, Inc.) automatic sampling system Model KS No. 569. The system consisted of manifold three-way solenoid valves, the necessary programmer and timers to operate these valves, a Buchler polystatic pump Model 2-6100 for sample collection pumping to a Buchler Model 3-4008V refrigerated automatic fractional collector.

The sample switching system diverted all streams to waste except the one stream being sent through the analytical train. The system was operated on a one- or two-hour cycle, and at the end of each cycle, a tap water flush was put through the system to minimize sample carryover. Actual sample collection took place during the last minute of each sampling increment and was accomplihsed by collecting approximately 35 ml of sample in a refrigerated 50 ml test tube. The collector had a capacity of 200 glass collection tubes. The sample collection pump operated continuously, with the stream being diverted to waste except during actual sample collection.

The main single sample stream flow passed through pH and turbidity sensing units. The pH output was provided by a recording pH meter producing an output in a strip chart recorder form. The pH probe was placed in a system overflow point providing constant liquid depth and adequate mixing. The turbidity measurement was provided by a Jacoby-Tarbox, Model A2 turbidimeter. The turbid sensing unit provided a flow cell with a 1/2 in. light path. The turbidity output was recorded on an Esterline-Angus Model A601C single-channel curviliner recorder. The turbidity flow cell had a simple clamp design, permitting rapid cleaning of windows. Cleaning was conducted approximately on a semi-weekly basis.

At the over-flow point in the sampling system where the pH probe was located, a continuous sample stream of approximately 7 mls/min. was pumped to the principal analytical instrumentation complex. Alternate sample introduction with distilled water-wash periods between peaks was selected to minimize sample carry-over, to improve analytical performance, and to aid in the identification of individual samples. This method of sample introduction was achieved by using a 4-way solenoid valve that normally directed distilled water into the analytical system and diverted the sample stream to waste, except for the last two minutes of each cycle, when the sample stream was introduced into the analytical system. A second solenoid valve was used to introduce a common standard solution for all the analytical systems. The analytical standard 3-way solenoid was actuated at the same time the tap water valve was operated in the TAFI switching system, to provide the cyclic flushing. The standard supply was stored in the refrigerated sample collection device, minimizing degradation so that a replacement frequency of once every two days was adequate. Polyethylene tubing (0.34 inches in diameter) was used to deliver the intermittent sample and distilled water stream to the individual analyzers.

The four basic Technicon Auto-Analyzer automatic wet chemistry systems that were used on a continuous basis provided analytical results for ortho-phosphate, ammonia nitrogen, combined nitrate and nitrite and

COD, and the output was received on two 2-pen continuous recorders. The ortho-phosphate was determined using Technicon Industrial Method 2-68W employing the ammonium molybdate and ammonia naphthol sulfonic acid method with a full-scale recorder output range of 0 to 30 mg/L phosphorus. The ammonia concentration was determined with the Technicon Industrial Method 19-69W, utilizing the alkaline phenol hypochlorite reaction with ammonia, adapted for a concentration range of 0 to 50 mg/L ammonia nitrogen. Combined nitrate and nitrite nitrogen was determined by Technicon Industrial Method 32-69W that involved an approximate 15-minute digestion procedure with a potassium dichromate-sulfuric acid digestion mixture and adapted to provide a full-scale range of 0 to 300 mg/L COD.

Another means of measuring organic matter was the use of a Union Carbide Model 1212 Total Carbon Analyzer on a continuous basis. The instrument provided for the automatic introduction of a 40-microliter sample into a reaction chamber where a nitrogen carrier gas transported the reaction product to an infrared detection system to measure total carbon. The timer mechanism of the total carbon instrument was connected to the sampling system switching unit to assure sample analysis synchronization. Total inorganic carbon values were determined only on an interim manual basis by injecting wastewater samples in an acid media through which the carrier gas by-passed the reaction chamber and went directly to the infrared detection section.

Two additional automated wet chemistry systems were utilized in the project laboratory for the determination of total Phosphorus and total Kjeldahl nitrogen. Although throughout most of the study these particular systems were operated on a manual sample introduction basis, they were coupled to the automatic sampling system in the last portion of the project. The two autoanalyzers included a total phosphorus system using the Industrial Technicon Method 4-68W operated at a low range of 0 to 40 mg/L phosphorus, and a total Kjeldehl system using Technicon Industrial Method 30-69 adapted for measuring a low concentration of 0 to 60 mg/L nitrogen. The systems were adapted to use a common sample input and a single continuous helical digester operated at a temperature of 400°C. The output stream was separated for respective simultaneous determinations, and results were indicated on a two-pen recorder.

The mode of operation of the continuous automatic sampling and analysis system was on the basis of four days a week (from 10 a.m. Monday morning continuous through 10 a.m. Friday morning). This period of operation was selected due to manpower constraints for system maintenance and data tabulation of chart outputs. During the first eighteen weeks of research study, the sampling system was operated on all eleven sampling points; however, sample introduction to the Technicon and Union Carbide analytical systems was done on a manual basis after certain sample preparation measures had been performed. During the final ten weeks of the study, the sampling points (including the common primary effluent point and the two secondary/final effluent sampling points). With the reduced levels of suspended solids, the Technicon and Union Carbide systems were operated on an automatic basis in conjunction with the other instrumentation and sample collection activities. At the end of the study, the sampling analytical system was operated on a continuous basis for the last 20 consecutive days of the study. In this manner, various modes of operation of the sample monitoring system were used during the study. The system is pictured in Figures B-3, B-4, and B-5.

Discussion

One of the initial problems with this monitoring system was the operation of the sample point pumps. Troubles were experienced with the six sample points located in the activated sludge aeration tanks because they had a tendency to pump air, thereby displacing the necessary liquid stream for the sampling system. This difficulty was corrected by attaching an approximate one-foot diameter screen deflecting device around the inlet area of each of the submersible pumps. Since the pumps were operated on a continuous basis, some plugging was experienced of the coarse screens around the pump inlets or in the "Y" strainers just before the switching collector device due to solids buildup. This condition was particularly true of the return sludge sample pumps in that over an eight- to ten-hour period there would be enough plugging to terminate sample flow. Because these sample points were located so close to the central switching system, requiring approximately one minute from the time the pump started until flow reached the switching device, the operation of these two return sludge sample point pumps was changed from continuous operation to operation only when the TAFI switching system actuated the solenoid valve associated with each of the sampling points. Even with these preventative measures, sample system plugging was a continuing problem. Therefore, in addition to the normal weekly flushing measures that were performed, all pumps and strainers were checked on a daily basis, and if necessary, cleaned to assure continuous representative sampling.

Another problem area was that of removing solids in the sample stream to eliminate sample carryover and achieve feasible operation of the Technicon and Union Carbide analytical systems. The first solution considered was the use of a Technicon continuous filter system which proved to be very ineffective on the return sludge stream and effective only at a very low flow rate for the mixed liquor sample stream. Various in-line filters and settling systems were applied to this problem in an attempt to find a solution. However, all of these approaches proved ineffective either due to high rates of plugging or inability to eliminate carry-over during the comparatively short (5 to 10 minute) sample cycle. Various in-line filters and settling systems were applied to this problem in an attempt to find a solution. The alternative centrifugal solid separation using a Dorr-Clone cyclone system was also attempted. This alternative was also found to be unsuccessful due to the nature of the biological solids. The eventually adopted solids removal procedure, when all eleven sampling points were being sampled, involved the quiescent settling in the refrigerated sample collector tubes for a period of 6 to 16 hours and then manual introduction of the supernatant into the Technicon and Union Carbide analytical systems. Even though the sample collection tubes were previously cooled prior to receiving the sample, analytical results indicated that some soluble nitrate, COD and ammonia alterations took place during this residence time in the sample collector. This situation was corrected by the installation of Whatman No. 4 filter papers in the top of each of the collector test tubes, which provided a gross solids removal prior to the settling period. Results from these prefiltered samples compared favorable with appropriately collected grab samples that were treated by immediate centrifugation and filtration. Therefore, the reason for the mode of operation previously described for the first 18 weeks, during which all 11 points were sampled, was the need to provide a feasible approach for solids removal from samples having such a wide range of biological solid concentrations. When only the overall inlet samples of the activated sludge system were collected by the system (Sample Points No. 1, 2, and 3), the Technicon and Union Carbide analyzers accepted the sample streams directly. This was achieved because the highest concentration of suspended solids was approximately 150 mg/L, as opposed to the 2,000 and around 8,000 mg/L ranges found in the mixed liquor and return sludge, respectively. Therefore, on a three sample point basis, continuous automatic monitoring using all analytical systems was accomplished during the last ten weeks of this study.

Some indication of the type of data output of the continuous sampling monitoring system is presented in Figures B-6 through B-12 which show sample charts from each of the different recorders used in the system. As indicated by the ortho-phosphate and ammonia nitrogen output curves in Figure B-6, the normal cycle for complete automatic monitoring consisted of a one-hour cycle broken up into ten-minute segments. For example, the first ten-minute segment is a sample of the secondary effluent from activated sludge system No. 1, followed by secondary effluent from system No. 2, then a sample of the common primary effluent entering the pure activated sludge system. The remaining segments consist of a repeat of the same sample, followed by a standard and then a water wash, and a repetition of the cycle. The normal analytical standard, as indicated on this graph consisted of 20 mg/L ortho-phosphate and 20 mg/L ammonia nitrogen. The high removal of phosphorus is quite obvious by the output result and the consistency between the two samples of the identical primary effluent which also indicates the precision of the system.

Figure B-7 shows a typical cycle from the COD and combined nitrate-nitrite-nitrogen output system. The standard used during the cycle depicted consisted of 1 mg/L of nitrate nitrogen and 250 mg/L of COD using primary standard phthalic acid as the carbon source. The tap water is shown to contain significant nitrate and little or no COD.

Figure B-8 presents the Union Carbide total carbon analyzer results for a typical monitoring cycle. Also, included are a typical analytical standard curve and a calibration curve. Although the total phosphorus and total Kjeldahl system was not normally operated with the continuous automatic monitoring system, Figure B-9 presents an one-hour automatic cycle showing the same order of samples and standard as presented in previous figures. It can be noted in Figure B-9 that there was considerably less phosphorus removal than in Figure B-3, because of the type of investigation being conducted at the time of the sampling.

The analytical monitoring results of the other instruments, included those from the dissolved oxygen analyzer, turbidity meter, and pH sensing unit. These results were essentially unchanged throughout the survey and were not altered by the mode of operation. Figure B-7 presents typical output of the dissolved oxygen monitoring system and shows that a sharp peak D.O. occurring at the center of the aeration tanks can be followed through the system by adding the approximate detention times in the respective units. The recorder response for sample probes placed in the aeration tank showed more variability than those in the final clarifier; however, they were still very adequate for assessing current dissolved oxygen values.

The typical turbidity output for both operation of the system with 11 points and operation of the system with 3 sampling points are indicated in Figure B-11. Under operation of all 11 points, the response was most obvious on the turbidity output when the number 10 return sludge pump became plugged. While monitoring the three sampling points only, the occurrence of a discharge of high solids coming into the activated sludge is similarly quite obvious. The principal uses of the turbidity output were for approximate sensing of the changes in suspended solids in the process and also for indicating adequate operation of the sample pumping system. Figure 12 presents some sample output of the pH recording system. The high pH of the tap water rinse system is most obvious, particularly in the 3-point cycle as opposed to the 11 sampling point operation.

The value of having monitoring systems on a continuous basis with immediate assessment of phosphorus, nitrogen, COD and carbon removals, is the ability to provide current knowledge for precise control of plant operation. An example of these changes is shown in the results of a study to assess the effect of dissolved oxygen level on the phosphorus removal ability of the plant. The results for one short period of time are presented in Figure B-13 and show distinct periods of phosphorus release and phosphorus recovery in the test system, while the control system continued to remove a high degree of phosphorus. Having an operable monitoring system for use in control of the plant has created a high appreciation for immediate assessment of a critical parameter, whether it be phosphorus, nitrogen, or carbon in the optimum operation of any wastewater treatment facility.

The monitoring system as installed in Baltimore, was very experimental in nature and design, and, with respect to maintenance, did not compare to a ruggedly designed industrial monitoring system. The marginal pumping capacity of the sample point pumps, the flow restrictions caused by the small solenoid valves used in the switching system and the solids removal problem would be significantly improved upon with the experience gained in the monitoring operation for this project. The Technicon Autoanalyzer systems as installed are more oriented for intermittent laboratory use as opposed to the continuous service demanded in this study.

The maintenance time was quite low on the ortho-phosphate, ammonia nitrogen and total carbon analyzing systems. Maintenance was the highest on the Auto-analyzer systems, involving digestion that included the COD, total phosphorus and total Kjeldahl nitrogen systems. However, one of the more tedious aspects of this project was the data translation requirements. For example, creating a total of approximately three miles of chart paper and having to go manually through this output to make the analog peak to digital tabulated data transfer, was exceedingly time consuming and occupied considerable manpower. The value of having the data output in a digital printout form directly at the time the analysis was performed is fully appreciated as essential, if there are manpower limitations and if it is desirous to go back and recover the data. Therefore, such devices should be given serious consideration when installing a permanent monitoring system. Regardless of a data recovery ability, the opportunity of immediately assessing plant performance rather than having to wait five days for BOD results or a half-day for other analyses is a very great asset in optimizing the performance of a biological wastewater treatment plant.

Monitoring Conclusions

1. A continuous automatic monitoring and sampling system has been presented and six months of operation has verified the feasibility of such a system.

2. Although most Technicon Auto-analyzer systems require more development before being applied as low maintenance, stable, rugged industrial monitoring systems, Auto-analyzers for ortho-phosphate and ammonia nitrogen, indicated that they would be effective as long-term monitors.

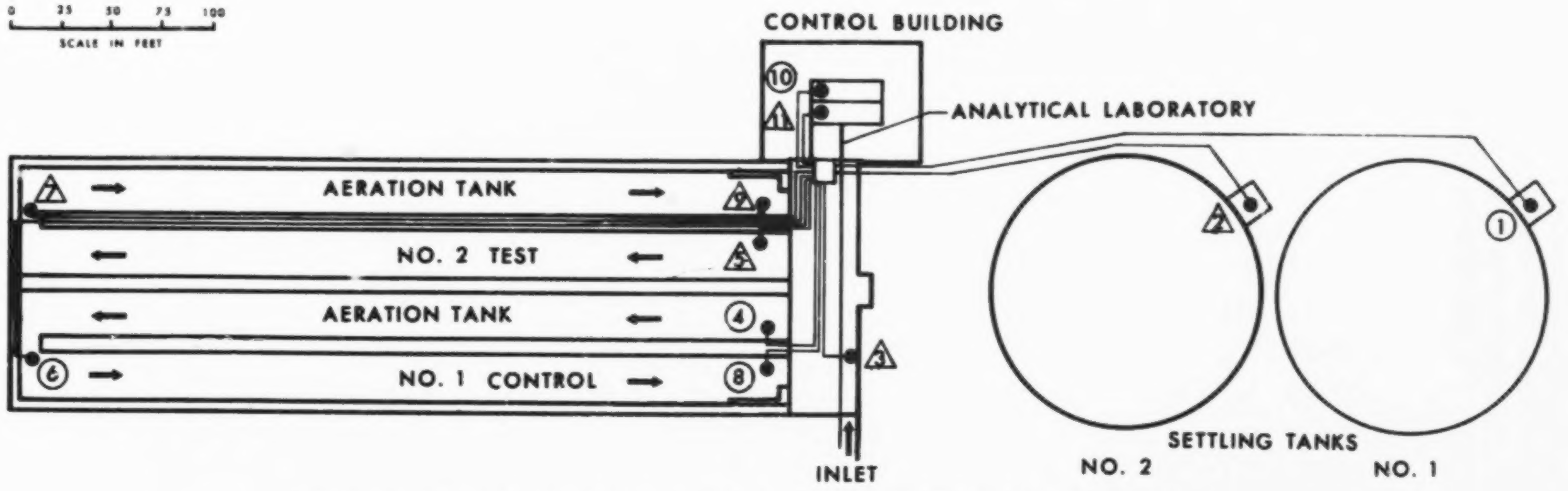
3. The total carbon analyzer system utilized as a part of the sampling monitoring analytical capability demonstrated reasonable application to waste treatment plant monitoring.

4. Dissolved oxygen, pH, and turbidity monitoring devices are at satisfactory levels of development for immediate use in activated sludge treatment plant monitoring systems.

5. The value of immediate assessment of the critical operating parameters is important for maintaining optimum performance of a wastewater treatment plant and for making meaningful operational changes for variations in inlet wastewater concentrations.

FIGURE B-1

PHYSICAL LOCATION OF SAMPLING POINTS


0 25 50 75 100
SCALE IN FEET
CONTROL BUILDING
⑩
11
ANALYTICAL LABORATORY
AERATION TANK
NO. 2 TEST
AERATION TANK
NO. 1 CONTROL
7
9
5
④
⑥
⑧
3
INLET
2
①
SETTLING TANKS
NO. 2
NO. 1

PROCESS DIAGRAM LOCATION OF SAMPLING POINTS

(NOT TO SCALE)

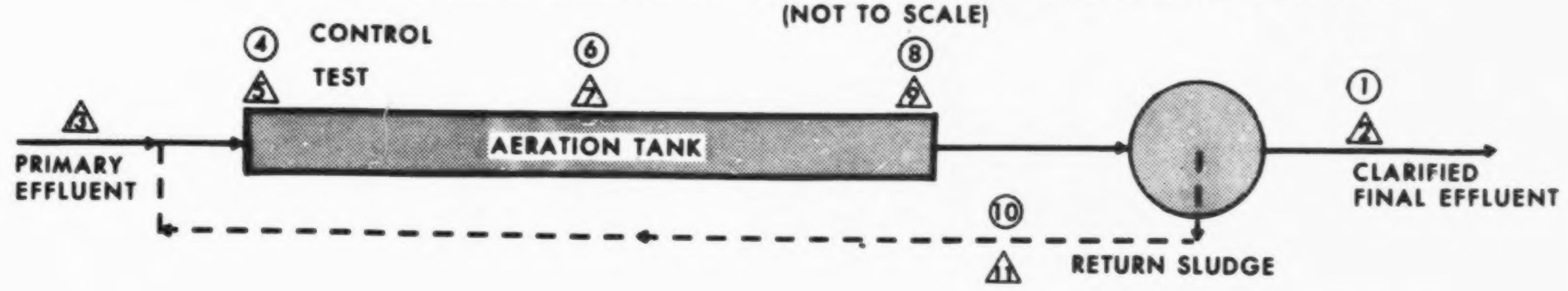
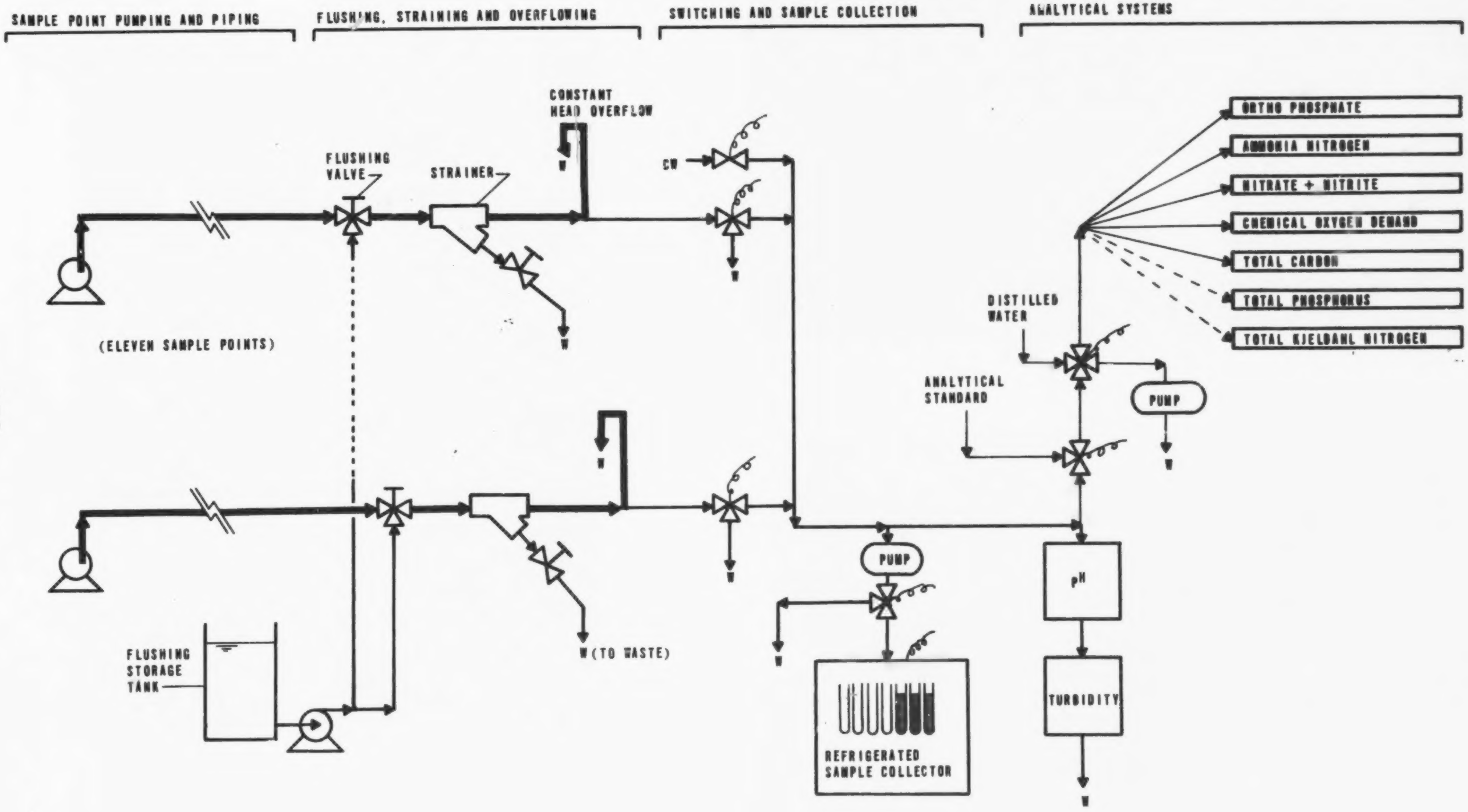
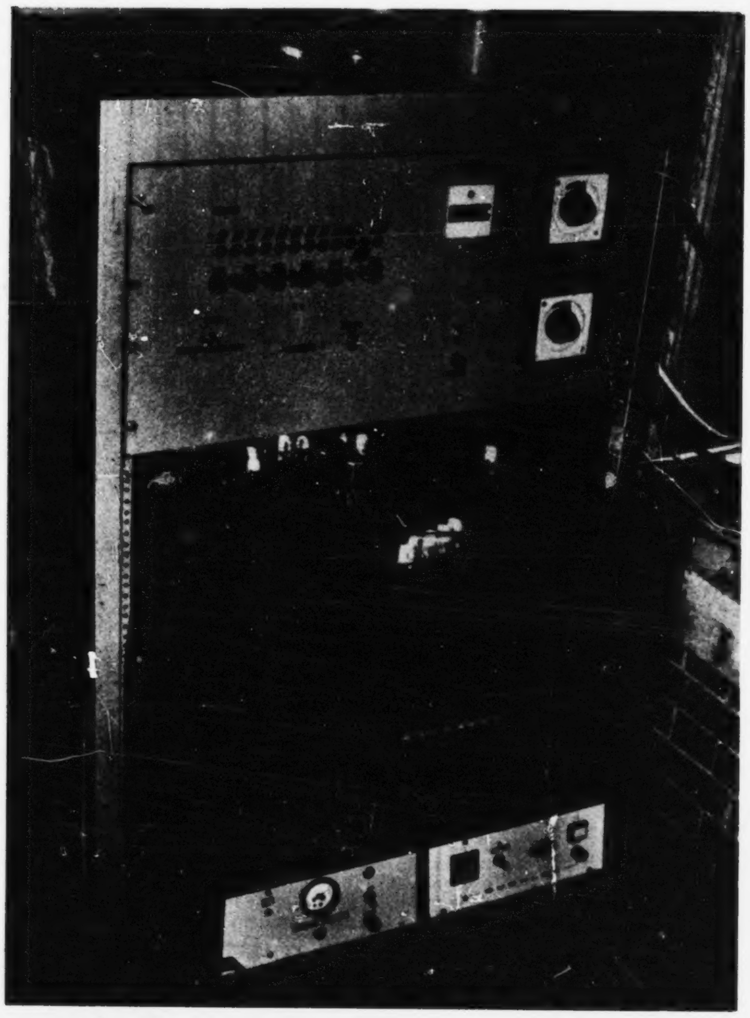

④
5
CONTROL
TEST
⑥
7
⑧
9
3
PRIMARY EFFLUENT
AERATION TANK
①
2
CLARIFIED FINAL EFFLUENT
⑩
11
RETURN SLUDGE

FIGURE B-2

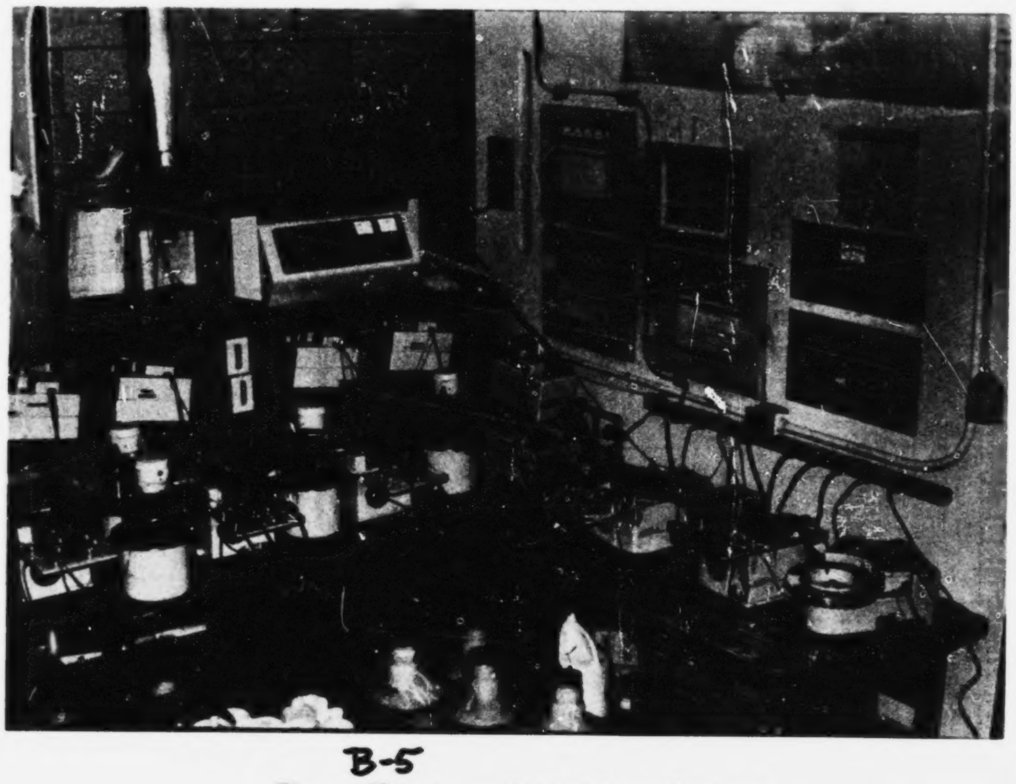
FLOW DIAGRAM OF COMPLETE SAMPLING AND ANALYTICAL SYSTEM


SAMPLE POINT PUMPING AND PIPING
FLUSHING, STRAINING AND OVERFLOWING
SWITCHING AND SAMPLE COLLECTION
ANALYTICAL SYSTEMS
CONSTANT HEAD OVERFLOW
FLUSHING VALVE
STRAINER
W
CW
(ELEVEN SAMPLE POINTS)
W (TO WASTE)
FLUSHING STORAGE TANK
PUMP
REFRIGERATED SAMPLE COLLECTOR
DISTILLED WATER
ANALYTICAL STANDARD
pH
TURBIDITY
ORTHO PHOSPHATE
AMMONIA NITROGEN
NITRATE + NITRITE
CHEMICAL OXYGEN DEMAND
TOTAL CARBON
TOTAL PHOSPHORUS
TOTAL KJELDAHL NITROGEN

B-3
Figure [illegible] Aeration Tank Sampling Point



B-4
Figure [illegible] Sample Switching and Collection System



B-5
Figure [illegible] Automatic Analyzer Systems

NOT REPRODUCIBLE

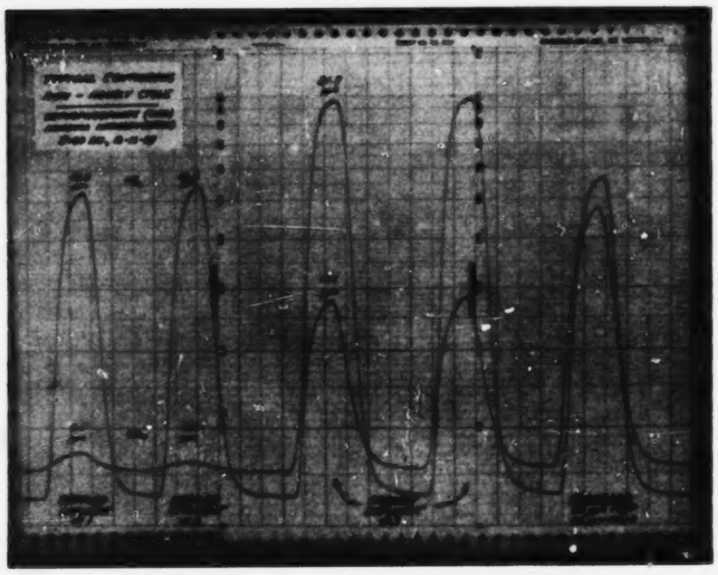


FIGURE ~~6~~ B-6

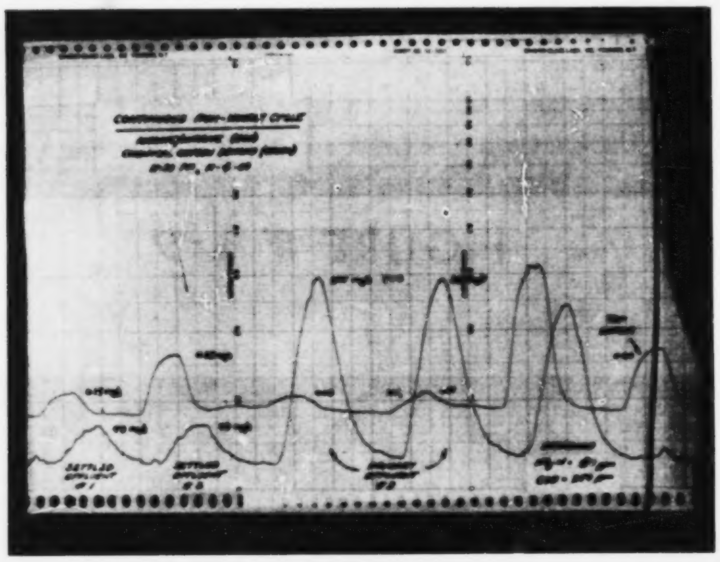


FIGURE ~~7~~ B-7

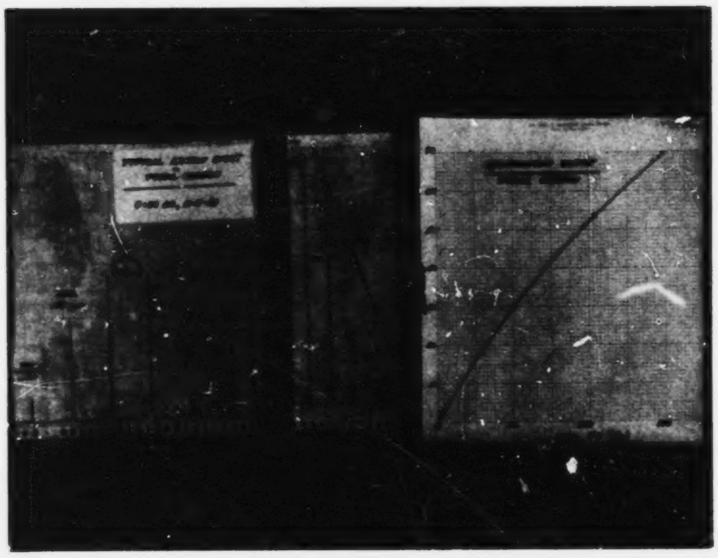


FIGURE ~~8~~ B-8

NOT REPRODUCIBLE

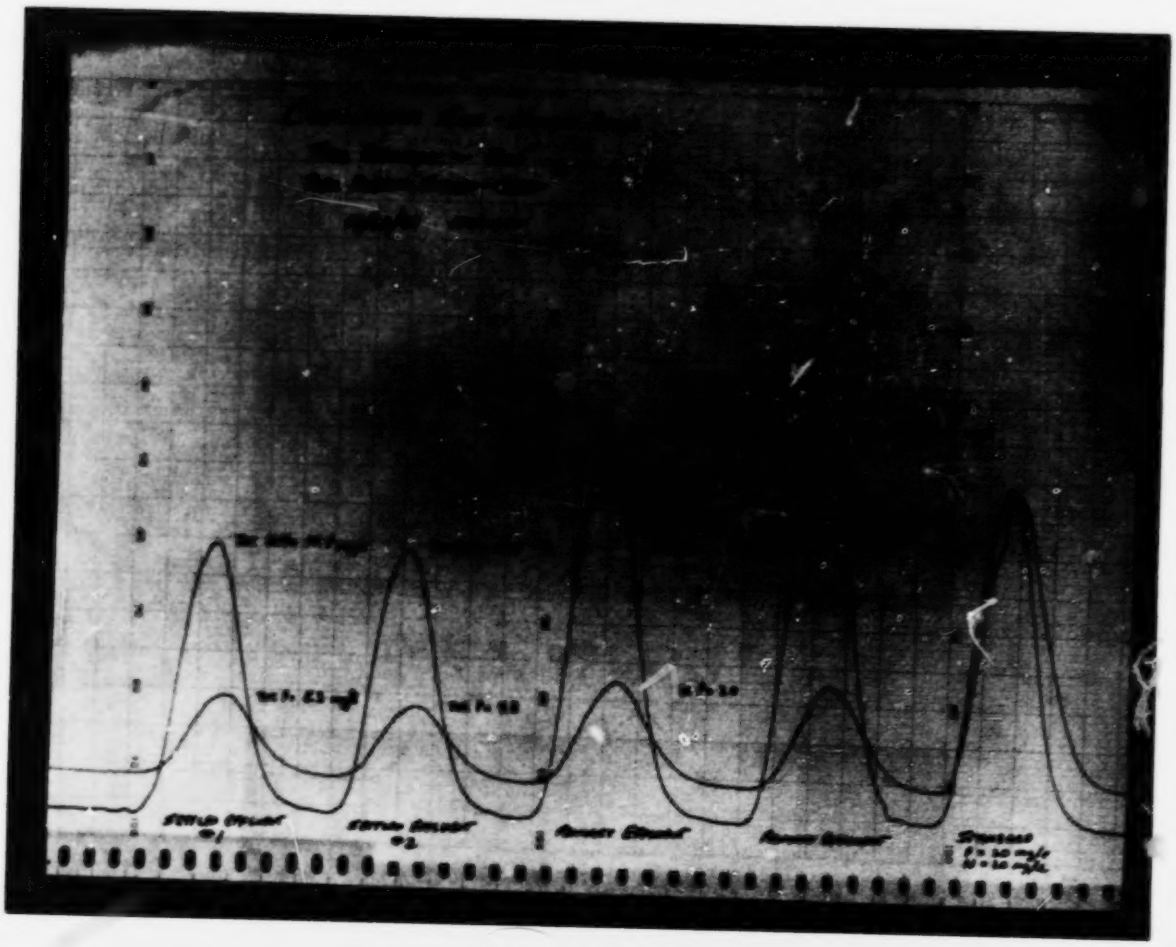


FIGURE B-9

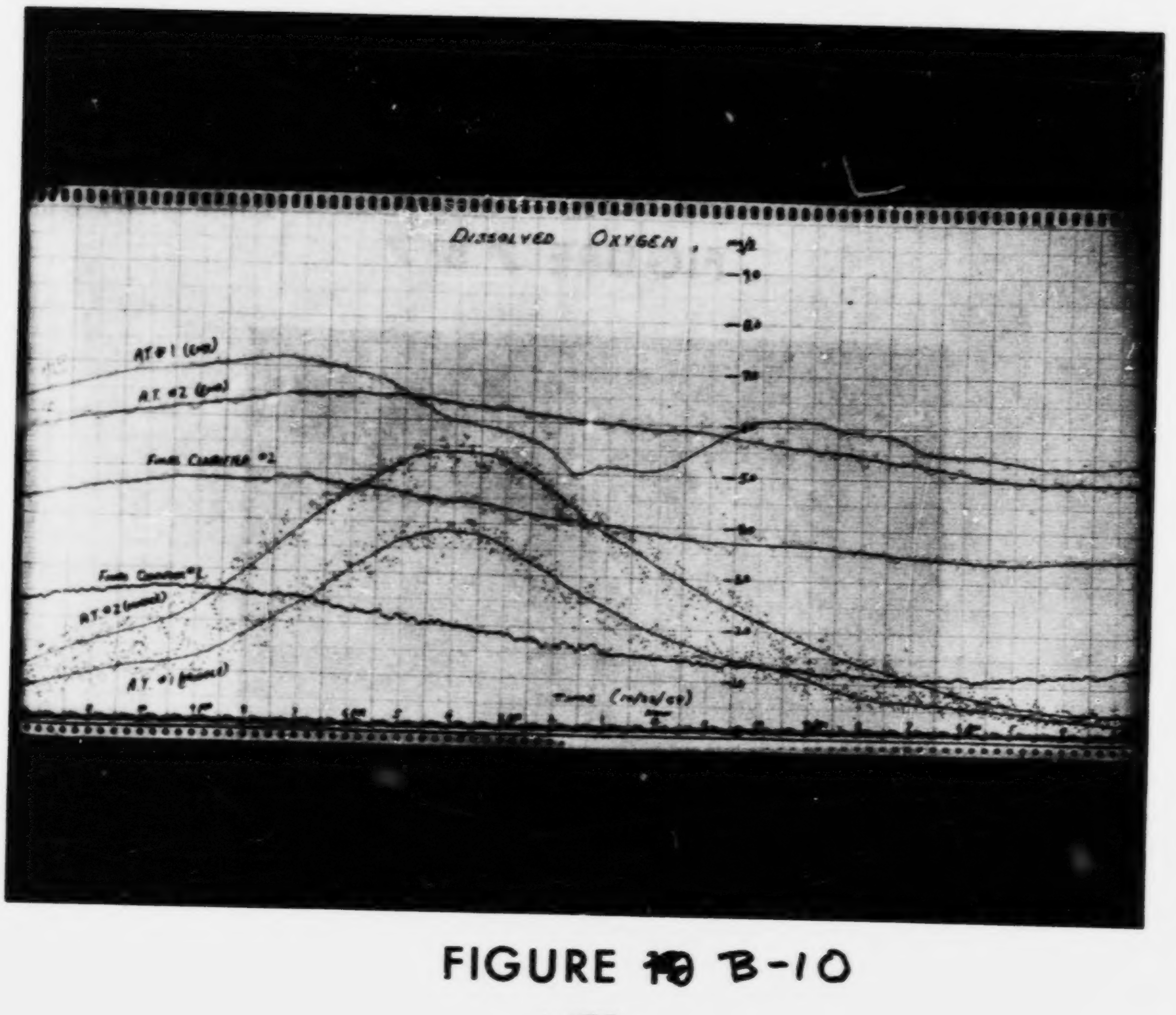


FIGURE ~~10~~ B-10

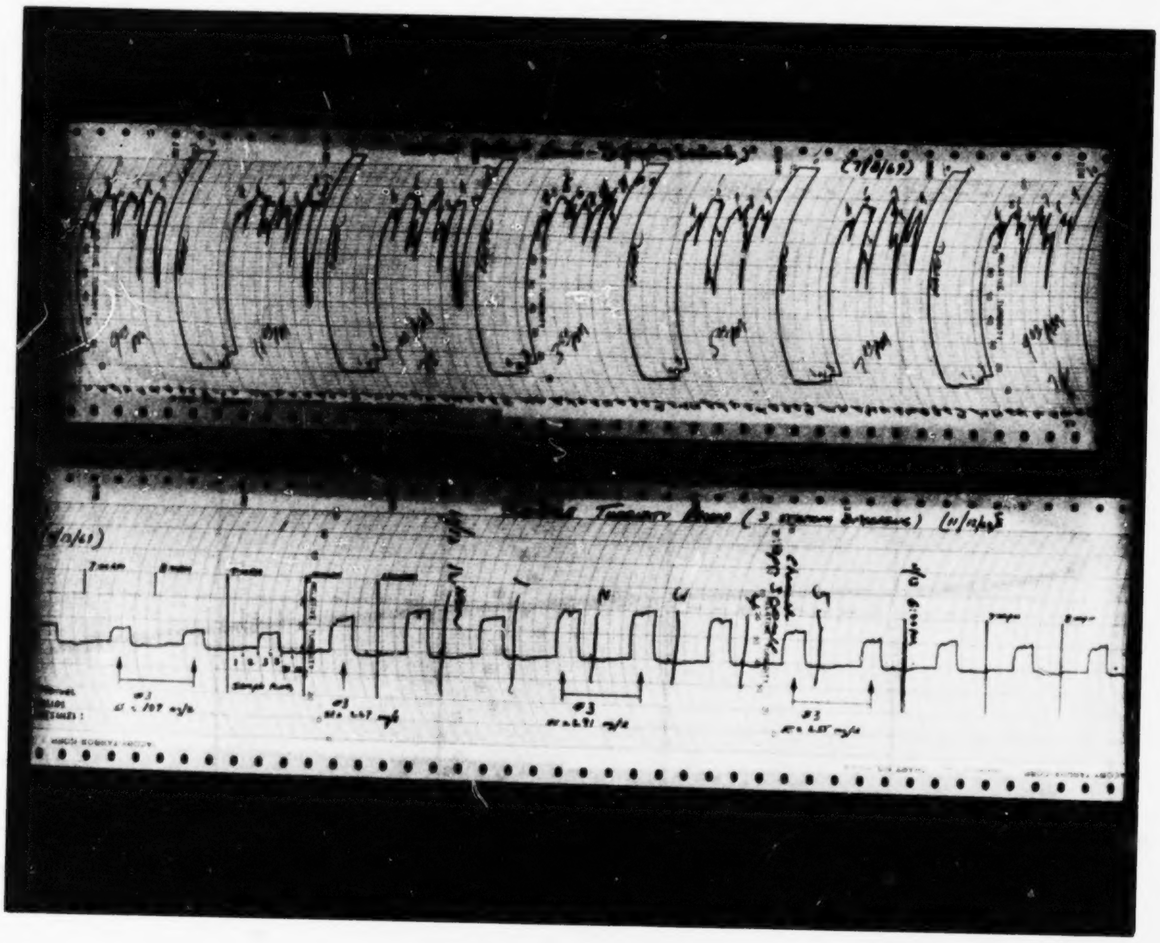


FIGURE B-11

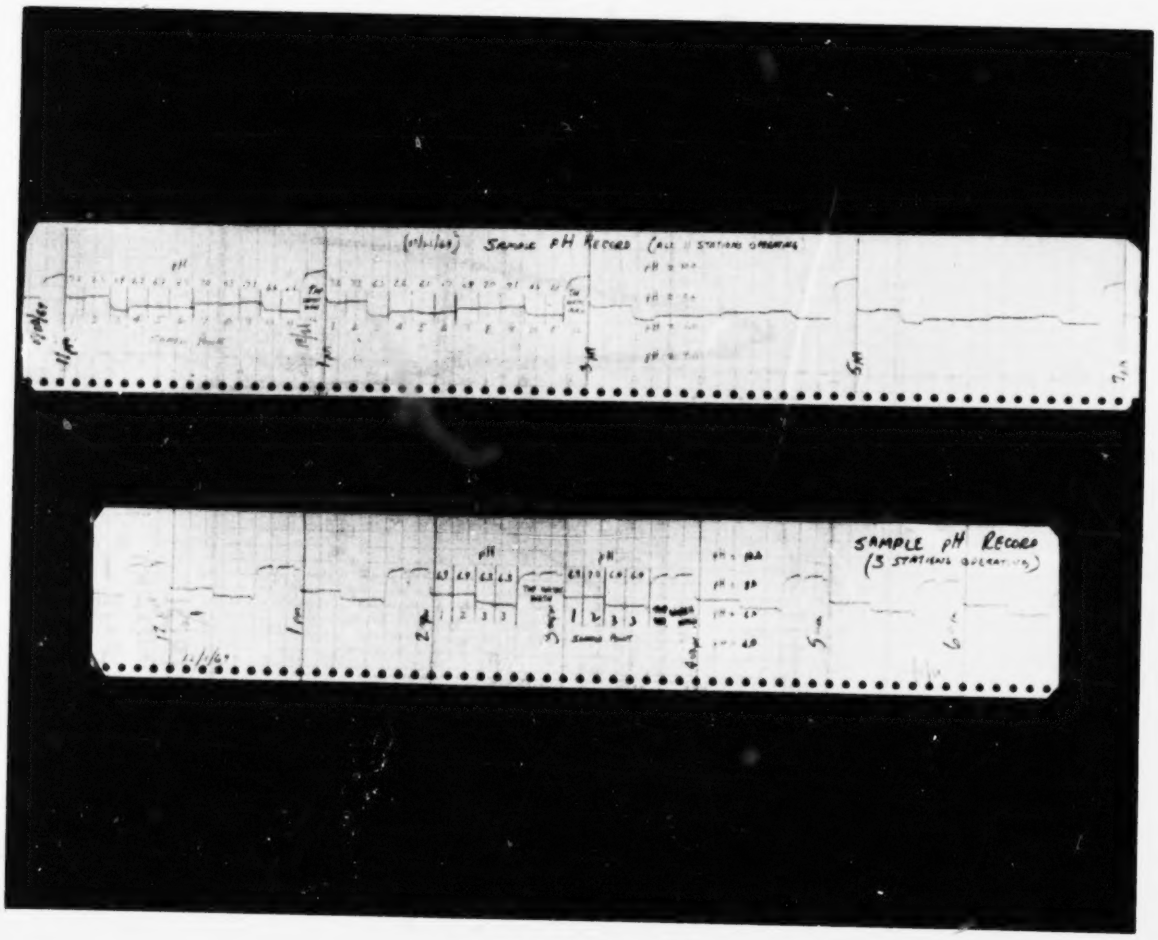


FIGURE ~~12~~ B-12

FIGURE B-13

PHOSPHATE REMOVAL IN FULL-SCALE ACTIVATED SLUDGE WITHOUT CHEMICAL ADDITION